Goldring, Winifred

Handbook of paleontology for beginners and amateurs

NEW YORK STATE MUSEUM

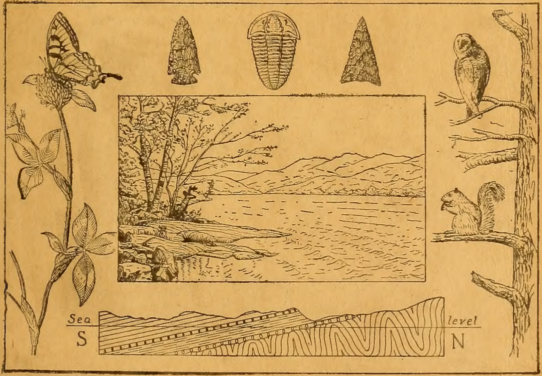
CHARLES C. ADAMS, *Director*

HANDBOOK OF PALEONTOLOGY FOR BEGINNERS AND AMATEURS

PART 2: THE FORMATIONS

BY WINIFRED GOLDRING

Associate Paleontologist, New York State Museum



ALBANY

THE UNIVERSITY OF THE STATE OF NEW YORK

1931

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Doctor Arthur Hollick
with the compliments of
Winifred Goldring

New York State Museum Handbook 10

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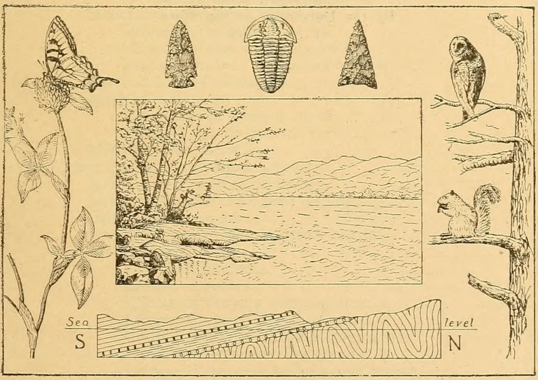

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Figure 1 Rensselaerville Falls, Albany county, N. Y. Upper Devonian section: Oneonta red beds. (Photograph by E. J. Stein.)

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PREFACE

The present handbook is a companion to Handbook 9 on Fossils and completes the *Handbook of Paleontology For Beginners and Amateurs.* As in the case of part 1, this handbook is written with *special reference to New York State.* The introductory chapter has three sections: one deals with the rocks, their origin, character, structures etc.; the second with conditions of life in the sea today; and the third with plant and animal associations along the shore. It has been deemed essential to a proper interpretation of the geologic formations, with their fossils, to have a general knowledge of these subjects. The chapters on the geologic formations are prefaced by a short discussion of the nomenclature, classification and correlation of geologic formations and the geologic time scale.

The material for this handbook has been drawn from many sources. At the end of each chapter and in the bibliography is listed such literature as is thought to be of interest to and within the scope of the reader. Numerous references will be found in the literature cited. The maps and sections used here have been adapted from those made by the writer for the case "What is a Geological Formation?" on exhibition in the New York State Museum. The maps show the general distribution of the

formations in the State. Where outcrops are small they have necessarily been exaggerated. The former extent of the seas of the different periods as shown in the maps is suggestive only. The sections are generalized and simplified and it has been necessary here, too, where formations are thin to exaggerate the thickness somewhat. Many of the photographs used were taken by Mr E. J. Stein, photographer and draftsman of the State Museum, to whose skill are also due the drawings for the plates of fossils. The photographs illustrating the chapters on life conditions in the sea we owe to the courtesy of the American Museum of Natural History and the Wisconsin Natural History Society.

The writer wishes here to express appreciation to Dr Charles C. Adams, Director of the New York State Museum, for the interest he has shown throughout the whole work and the encouragement he has given. From Doctor Ruedemann, State Paleontologist, likewise, the writer has had interest and encouragement, and she is also indebted to him for reading and criticizing the manuscript. Mr D. H. Newland, State Geologist, and Mr C. A. Hartnagel, Assistant State Geologist, have assisted in various ways. Dr E. O. Ulrich of the United States Geological Survey, Washington, has read and criticized the manuscript dealing with the Paleozoic formations. The writer is greatly in his debt for many suggestions and for the use of information which has not yet been made available. Thanks are also due Dr Charles Butts of the United States Geological Survey for reading the chapters on the Devonian and Carboniferous. The author has also had the advantage of the viewpoint of Mr Clinton Kilfoyle, technical assistant in Paleontology, who has read the manuscript for both handbooks and has rendered assistance in many ways.

INTRODUCTION

THE ROCKS

Geologically the term rock refers to the material composing the earth's solid shell. Thus defined it includes the *solid* or *bed rock* and the *unconsolidated* or *mantle rock* which is derived directly from the solid rock beneath through disintegration and decomposition and grades gradually into it, as is the case with the residual soils of our southern states, or which has been transported through some agency and rests abruptly upon it, as in the case of glacial deposits, stream deposits etc. It is the solid rock which will be considered here. According to their mode of origin rocks fall into three natural groups: *sedimentary, igneous* and *metamorphic.* The sedimentary rocks include bedded rocks formed by the deposition of mechanical sediments through the agency of water or the air, as sandstones, shales etc. Here also belong chemical precipitates and evaporation products from solution in water, as cave deposits (stalactites, stalagmites), rock salt, gypsum etc. and deposits formed through organic agencies in the air or water, as coral and shell limestones, chalk, coal, guano etc. Igneous rocks (Latin *igneus*, fiery), are rocks, such as granite, usually crystalline and composed of a number of minerals and formed by the solidification of molten material. Metamorphic rocks (Greek *meta,* over; *morphe,* form), are known as secondary rocks because they are derived from rocks of the two preceding groups by certain processes that bring about recrystallization of the rock constituents either with or without alteration of the chemical composition of the mass, as in the formation of gneisses from granites, marbles from limestones, schists from sandstones etc.

Sedimentary Rocks

Origin of materials. Sedimentary rocks may have one of three origins, mechanical, chemical or organic. Those of a mechanical origin, the clastic rocks (Greek *klastos*, broken), are derived from sediments deposited through the agency of water and the air and here belong conglomerates and breccias, sandstones, shales and limestones, the rocks which are of most importance to us here and which will be discussed in greater detail below.

The great bulk of our limestones are of organic and, secondarily, of mechanical origin, but some are chemical precipitates. Calcareous tufa is one of the most extensive of these. It is formed by springs that issue in limestone regions and deposit the excess of lime that they hold in solution. Calcareous tufa is mostly porous and not infrequently incrusts plants and other objects, but there are also massive deposits forming the so-called "Mexican Onyx." Other carbonate of lime precipitates of a compact character are the stalactites and stalagmites of caves. Sometimes beds of limestone are composed of large, rounded concretions formed by the deposition of carbonate of lime, generally around a nucleus; or again such concretions may form distinct layers in shales as is seen in places in our Marcellus and Portage beds. Dolomite which is a carbonate of lime and magnesium is formed as a primary deposit in cut-off basins of sea water, especially where there is an excess of chlorides in the water, and as an original precipitate in portions of the sea where the solution has become concentrated. In some cases dolomitic limestones are of secondary origin. The magnesia content of the original limestone was probably mostly derived from calcareous algae, but through solution of the carbonate of lime by ground water the pro-

portion of magnesia was increased. Magnesium carbonate is also secondarily deposited from solutions in circulating ground water.

Rock salt and gypsum are also precipitates found in many parts of the world and of great commercial value. They are found in the Salina beds of central New York where they are mined. The rock salt, a chloride of sodium, commonly occurs in a succession of beds, sometimes of great thickness, which are separated by gypsum, anhydrite (sulphate of lime) which slowly changes to gypsum by taking on water, limestone, dolomite or clay. These deposits are due to the concentration of sea water in basins cut off from the sea or in lagoons behind a bar with an inlet permitting a continual supply of sea water. Gypsum (hydrous sulphate of lime) is found beneath the beds of salt because in the concentration of the sea water it separates out of the solution first. Salt is also deposited in lake basins in arid regions through evaporation, as in Great Salt Lake, Utah; and in desert basins, such as Salton Sink, salt deposits are formed from the salt disseminated through the rocks in their rims. Gypsum is formed secondarily by alteration of limestones by percolating waters charged with sulphuric acid. There are large gypsum beds of this kind in New York State. There are numerous other chemical precipitates, among them the potash and borax salts, saltpeter and metallic deposits, such as oxides of iron (limonite, hematite), but it is unnecessary to discuss them here.

Materials of organic origin that enter into the formation of rocks are of two kinds, *organic precipitates* and *organic tissues.* Animals and plants take carbonate of lime or silica from the water in which they live and in which these minerals are held in solution and from this

material build up their hard parts, the organic precipitates taking the form of shells, the skeleton of corals, bones and other hard structures. Organic tissues when properly buried become altered, leaving a product which is composed of a mixture of carbon and hydrogen, such as coal which is a product of alteration of plant tissues. Among the plants there are certain bacteria which live in warmer seas and through chemical action bring about the separation of calcium carbonate or lime from the sea water in small spherical or elongated grains which upon accumulation form a deposit of oölite. Oölitic rocks resemble in structure the roe of fish and give a very pleasing effect in building stones. Oölitic deposits due to bacteria are forming along the coast of Florida in great abundance. A number of species of algae or seaweeds in the geologic past and today are lime-secreting or calcareous forms, a large part of the mass of coral reefs being formed by them. Since many of these lime-secreting seaweeds also precipitate a carbonate of magnesium, the rocks formed are dolomitic in nature and, as pointed out above, become more so through solution of the calcium carbonate content. The *Lithothamnion* of our modern coral reefs also formed extensive limestone masses in the past. *Corallina* is a common lime-secreting seaweed along our coast. The fresh-water stonewort (*Chara*) not only forms deposits of marl on the lake bottoms today, but is responsible for limestone beds in past ages. A calcareous seaweed (*Cryptozoön*) forms reefs in our Upper Cambrian rocks (Little Falls dolomite) which are well exposed in Lester Park and other areas around Saratoga Springs. Silica deposits of organic origin are far less common than organic lime deposits. Diatoms, plants of low organization, have silicious skeletons which

accumulate on bottoms both in fresh-water ponds and seas forming a diatomaceous ooze. The rock formed is known as diatomaceous earth or tripolite, when pure, (named from its occurrence at Tripoli in North Africa). Skeletons of radiolarians and sponge spicules also generally occur in such deposits.

Foraminifera secrete shells of carbonate of lime which accumulate to such an extent that they form oozes on the ocean bottoms, such as the Globigerina ooze of today and Globigerina limestones (Tertiary) of the past. The chalk cliffs of France and England (Cretaceous) are mainly of foraminiferal origin, as are also the nummulitic limestones (Tertiary) of northern Africa and southern Europe and the Fusulina limestones (Carboniferous) of western North America and Europe. Some of the limestones of the Gulf States and the West Indies are formed of species of Foraminifera related to the Nummulites. Corals with associated lime-secreting forms, such as the hydrocorallines among animals and calcareous algae among plants, are responsible for reefs and lime deposits today and in the past. Older limestones show by certain structures that they are partly formed of old reefs, partly of bedded lime deposits consisting of a mixture of coral sands, shell fragments, etc. Sometimes these ancient reefs are very clearly defined; again they may be so altered that they can be recognized only through their general form and structures in the surrounding rock. Fossil reefs are found in the Silurian of Wisconsin and adjoining areas and in the Middle Devonian of eastern United States. These Devonian reefs were formed successively in the great interior sea of that time along the coast of the land

mass to the east. Several of these reefs have been definitely located; one extending through eastern New York and Pennsylvania, a second in western New York, a third passing through northern Ohio and a fourth through northern and western Michigan. Tube corals and hydrocorallines (*Stromatopora*) are abundant in these reefs but the forms chiefly found are the honeycomb corals (*Favosites*) and star corals (*Craspedophyllum* etc.) Bryozoans secrete structures of carbonate of lime and recent forms are found incrusting seaweeds, rocks etc. Fossil bryozoans formed branching, often cylindrical, masses or grew in sheet-like associations which formed the basis of limestone beds. Bryozoans, like corals, have formed reefs. Brachiopods and mollusks are the important shell-bearing animals. Shells of brachiopods, pelecypods and gastropods have formed beds of limestone in the geologic past. The shells of pteropods form a deep-sea pteropod ooze today and in the older geologic series the shells of such animals entirely make up limestones, as the Upper Devonian Genundewa limestone ("Styliolina limestone") of western New York. This limestone contains immense numbers of the minute pteropod *Styliolina fissurella.* Cephalopods, such as the Ammonites of the Mesozoic, have been so abundant as to build up beds of limestone. In certain New York formations, as the Watertown limestone of the Black River beds (Ordovician) and the Cherry Valley (Agoniatite) limestone of the Marcellus shale (Devonian), the cephalopods are in places very abundant. Crinoids together with blastoids and cystoids have been important as rock-formers during Paleozoic and Mesozoic times, forming what are

known as crinoidal limestones. Of all the parts of the animal, bases, stems and parts of stems are generally most abundant and prominent. In the upper part of the Becraft limestone (Lower Devonian) of New York crinoid bases are so abundant that formerly the name Scutella or Encrinal limestone was given to the formation. The Tichenor limestone (Middle Devonian) between the Moscow and Ludlowville divisions (as previously defined) of the Hamilton in western New York is another such a crinoidal limestone; and there are crinoidal layers in the Niagaran (Silurian) beds. Other instances of rock formed through organic agency, such as limestone beds rich in phosphate formed through the accumulation of the bones of vertebrate animals, might be mentioned, but the above examples are among the most important.

Accumulations formed directly from organic tissues may be of plant or animal origin. Plant material that is buried in a marsh or swamp decays very slowly giving off carbon dioxide (CO_2), water (H_2O) and marsh gas (carbon and hydrogen, CH_4) until the proportion of carbon is relatively increased. As this change goes on, together with the pressure of overlying material, the plant tissues pass through various stages of coal; and if the process is continued far enough all other substances except the carbon may be driven off leaving pure carbon or graphite, some of which is due to purely inorganic, chemical processes. Peat is the first product in the partial decay of vegetable matter. Brown coal is an altered peat deposit and still shows signs of its organic origin. It is common in Tertiary formations. Lignite is found in beds of Tertiary and Mesozoic age. It is altered woody tissue which is gen-

erally recognizable in the lignite. The bituminous coals are our common soft coals. A large proportion of the Carboniferous (Pennsylvanian) coals are of this nature and most of the younger (Mesozoic) coals. Anthracite coal, our hard coal, is found where much disturbance has taken place in the rocks and the bituminous coals have become metamorphosed. The Carboniferous coals are the most important and most extensive, forming the bulk of the coals of the world. The other two coal-forming periods were during Cretaceous and Tertiary times. Cannel coal is generally considered to be formed from fresh-water algae, also to a large extent from spores and pollen grains of higher plants that have blown into the bodies of water. Hard parts of animals are also found. Algae, spores of plants and animal tissues are probably the chief source of petroleum.

Consolidation of materials. Sediments, whether of mechanical, chemical or organic origin, before they become rock in the strict sense must in some way become consolidated.

Unconsolidated *mechanical sediments* include muds, sands and gravels. Upon consolidation muds become shales, lime-mud rocks etc.; sands become sandstones or, in the case of lime sands, limestones; gravels become conglomerates or breccias etc. The process of consolidation is known as induration. Clastic sediments may become consolidated in various ways, but pressure, cementation and recrystallization are among the chief ways. The last-named process belongs with the changes due to metamorphism and will be treated under metamorphic rocks. Pressure alone may cause induration, but probably in all cases of rocks thus

formed there is a certain amount of cementatión by mineral matter. The weight of younger sediments upon the older ones forces the grains in the older sediments closer together causing them to adhere more or less firmly. Sands thus indurated form a soft sandstone known as freestone. Finer sediments, such as clays, become more strongly consolidated by this process and form shales.

Consolidation by cementation is a very common process, particularly at greater depths. Percolating waters dissolve certain mineral constituents of the sediments and redeposit them farther down to act as a binder between the grains. Temperature increases with depth and increases the chemical activity of water. Pressure is also an aid in consolidation by cementation. The common cements binding together the particles of sediments are calcite or carbonate of lime, silica and iron oxides such as ferrous oxide, hematite and limonite. In calcareous deposits carbonate of lime is the chief cementing material, but it also may bind together quartz grains in calcareous sandstones and pebbles in conglomerates. Where silica is the cement sedimentary rocks are very hard, especially if the material consists of quartz grains. Here the silica is deposited around the grains so that the new quartz and the quartz grains are continuous. As the process is continued the grains finally become indistinguishable and a bed of quartzite is formed. Ferrous oxide has no distinguishing color, but hematite is red and limonite is brown or yellow and their presence as a cement gives the familiar yellow and brown colors to our sandstones. The brownstone so familiar in buildings is a sandstone so cemented.

Chemical sediments are sometimes precipitated in crystalline form and if the deposits are pure they are nearly as hard as the mineral itself. When the deposit is uncrystalline (colloidal) it may harden by the gradual loss of water, as in the case of bog-iron ore, or it may finally become crystalline. *Organic sediments* of mechanical origin, such as coral sand, are consolidated as clastic sediments. Organic precipitates are of a chemical nature and consolidated in the manner of chemical sediments.

Places of deposition. The clastic or mechanical sediments, particularly the marine deposits, are those which are of the most importance to us here. As all sedimentary rocks they may be classified, according to place of deposition, into continental, littoral and marine deposits, and this distinction is of great geologic importance.

Continental deposits include lacustrine, fluviatile and terrestrial deposits, the last-named group comprising many important deposits of mineral matter. Among clastic deposits of this group are residual rocks or those in which the material was formed by disintegration and decomposition with little or no transportation; eolian rocks or those derived from sediments deposited by the wind upon the dry land; and rocks formed of all sediments deposited upon the land through the agency of moving waters, such as deposits in lakes, ponds and playas, river flood-plain deposits, alluvial fans and deltas. Residual rocks produced by the destructive action of the atmosphere are consolidated without sorting or rearrangement of material. A good example is consolidated laterite. Laterite is a red soil or deposit produced in tropical regions through subaerial decay of rocks such as granite which leaves a mixture of quartz grains and a claylike substance colored reddish by iron oxides. Eolian

deposits are most prominently illustrated by dunes and loess. The sand grains composing dunes are mostly quartz and are well rounded. Rocks formed from such deposits are characterized by the rounded character of the quartz grains and lack of fossils. Loess is a pale to buff-yellow or brown deposit composed of quartz, feldspar, clay, calcite, mica etc. The particles are finer than those in ordinary sands, sharply angular and there is an absence of stratification characteristic of water-laid material. Such deposits have few fossils and those that are found are land forms such as snails or bones of animals. Concretions of carbonate of lime and oxide of iron are characteristic features of these deposits and often assume odd shapes.

Among deposits due to the agency of water are desert deposits in arid interior drainage basins. The land waste of the slopes of the basins is constantly moving toward the interior either into permanent lakes which they slowly fill up or into temporary lakes or playas. Rainwash, streams and wind drift play a part in the formation of these deposits. Layers of salt and gypsum often characterize such deposits and they are apt to show red coloration, less often yellow. This coloring is due to oxidization of the iron compounds in the rock and the lack of vegetation which through its decay would reduce or deoxidize the iron compounds and decolorize them. In humid regions, that is, where the rainfall is considerable, basinlike depressions of the continents become lake basin areas which receive deposits from streams. The shallow, more swampy areas show mud and clay deposits intermingled with organic matter from decaying vegetation. Rivers draining high mountain ranges are overloaded with material which they drop when they reach the foot of the

mountain, building up through their continued action extensive deposits of sand and clay of great thickness which are known as piedmont deposits (Latin *pes*, foot; *mons*, mountain). Deltas deposited by rivers whether in lake or sea are regarded as so much reclaimed land and belong with continental deposits. They have a characteristic structure which will be taken up later under structures of rocks. Fossils of delta formations will be terrestrial if the formations were laid down in a lake, and an intermingling of land and sea life if the delta was deposited in the sea. Always, the presence of land life only in formations indicates continental deposition. Glacial and fluvio-glacial deposits also belong with continental deposits.

Littoral deposits are the beach or strand deposits laid down between the tidal limits. The area covered by such deposits varies in extent depending upon the tidal range and the slope of the land. Where the slope of the land is very gradual there are tidal lagoons, salt marshes and shallow sounds and estuaries where mud flats are exposed at low tide. Here sands and muds are deposited. In general along the beach the area exposed by the tides is relatively narrow, and besides is so exposed to the action of the waves and tidal currents that the finer materials are washed away and only the coarser sands and gravels accumulate. Such deposits form conglomerates and coarse sandstone rocks but they are never very thick. Where land is building out to sea they are buried under land deposits, and when the sea encroaches upon the land they are buried under marine deposits.

Marine deposits are those laid down beyond the limit of low tide. The most active deposition goes on in the shallow sea or *flachsee* which covers the continental shelf

to a depth of 100 fathoms. The bulk of the material, chiefly sands and muds, deposited over this area are of land origin. Materials are brought to the sea by rivers, glaciers, icebergs etc.; by the wind, often from great distances; by the erosion of the sea shore by the waves; and by the scouring action of ocean currents. Going out to sea the material becomes finer and finer due to the sorting action of the water until finally only the finest muds are found. The zone of the finer muds is between the 100 and 1000 fathom depths, but the lower limit of the muds often extends beyond the 6000-foot line. Here are found blue, green and red muds and gray muds composed of volcanic ashes. Beyond this depth is the profound abyss where are found the various calcareous and silicious oozes and the red clay, chiefly of volcanic origin (fine dust), which is characteristic of the greatest depths. Some marine deposits, such as the limestones, are of organic origin. These deposits have been touched upon above. The breaking up and redeposition of such deposits makes them secondarily of mechanical origin. Marine fossils present in rocks are a certain indication of the marine nature of the deposits.

Description of clastic rocks. Some of the more important rocks of chemical and organic origin have been described above. Rocks composed of mechanical sediments, the clastic rocks, form the bulk of the sedimentary rocks and are of the greatest importance. As already pointed out clastic rocks are composed of materials which are fragments of preëxisting rocks, igneous, metamorphic or sedimentary. The agent that transports these materials may have the power to separate the heavier and lighter fragments. This is true of material carried by the wind or running water, and this process of separation of

materials is known as sorting. In the case of water, for example, the swifter the current the heavier the material that can be carried. If the force of the water is decreased for a time finer material may be deposited upon the coarser material, and with increase of current coarser material again follows the finer. This gives a layered or bedded appearance to the deposit. Each layer or bed is known as a stratum (plural strata) ; hence the deposits are known as stratified deposits and the rocks as stratified rocks. The different layers may differ in texture of material, in composition of material or in both texture and composition. Where conditions are very uniform there is a very uniform character to the deposits and a lack of bedding. This is true also when the materials supplied have been of a uniform character. Sometimes deposition is too rapid to permit of sorting as in the accumulation of talus. In certain glacial deposits, such as till (drumlins and material dropped by the melting of stagnant glaciers etc.), the transporting agent lacked the power of sorting. Alluvial cone deposits, because of their method of accumulation, show poor bedding; and fluvioglacial deposits such as kames and eskers rarely show good stratification because of rapid deposition, and slumping after the ice has melted away may even have obscured what was there.

The material composing clastic deposits may be derived from preëxisting rocks through shattering forces within the earth's crust or through processes acting at the surface. The material derived from disintegration and decomposition may be deposited with little wear to the fragments or the fragments may be so carried about and worn that their appearance is quite altered. By the composition of the sediments the

character of the rock from which they were derived may be determined and also something of the conditions under which they were deposited. Residual sands usually are composed of the minerals making up the parent rock, but in material which has been transported for a long time only the more resistant minerals are left. This is why quartz is so common a constituent of sands. When a deposit shows an abundance of decomposable minerals a very dry climate is indicated. In a warm, moist climate decomposable minerals in time decay and are dissolved so that a high percentage of quartz is left. An abundance of mica in muds and mud rocks indicates a continental deposit. Other hard minerals besides quartz that make up sands are magnetite and garnet, the source of which may be such metamorphic rocks as gneisses and schists. Granites are often the source of quartz; other igneous rocks and schists of mica.

The fragments making up clastic deposits may vary in size from large boulders through pebbles, gravels and sands to the finest muds and clays. The particles and fragments may be angular, subangular or rounded. Pebbles may be subangular or rounded and boulders likewise. Some formations show scratched, faceted pebbles; others polished, faceted pebbles. Angular particles are seen in residual sands, that is, material where there has been little or no transportation to round off the angles and sharp edges. Angular fragments are found in talus and landslide débris. Volcanic sands and coarser fragments are angular, also some ice-worn material. Where there is movement within the earth solid rock may be crushed producing the angular and subangular fragments which form the

fault breccias (see page 33). Wind-blown sands (eolian sands) and river and beach sands have rounded grains due to long handling. Material transported by glaciers and later deposited by running water (fluvio-glacial deposits) is apt to show subangular sands and pebbles. Pebbles and boulders carried by ice show faces or facets due to rubbing against bedrock as they are carried along. The pebbles may shift their position in the ice and then more than one facet is present. These faces also show scratches. Sometimes pebbles carried by ice show concave fracture scars. Pebbles in conglomerates sometimes show scars and indentations due to solution and pressure when they are in contact under compression. Polished faceted pebbles indicate wind action and are polished by wind-blown sand or dust. If there is one polished face the pebble is known as *einkanter* (one-edge); three faces give it the name *dreikanter* (three-edge). Pebbles and boulders become rounded not only through mechanical action in being rolled about, but also through concentric weathering. The agents of disintegration work in along the corners, edges and surfaces of blocks or slabs and as the corners and edges wear faster than the surfaces subangular to rounded boulders or pebbles of disintegration are formed. Such boulders and pebbles are weathered on the outside and have a rough surface in contrast to those that are rounded through mechanical action. The weathered portion of such boulders often peels off as a shell.

The rocks derived from the consolidation of these clastics, however accumulated, may be roughly divided into three groups according to the character of the constituents. These are the rubble rocks or conglomer-

ates and breccias, the sandstones, the mudstones or shales etc. To these may be added the limestones secondarily of mechanical origin.

Conglomerates are composed predominantly of rounded pebbles anywhere from the size of a pea to boulders of large size. In the latter case the conglomerate is known as *boulder conglomerate,* but when the pebbles are very small the rock is called a grit. These pebbles are usually water-worn and of river or seashore origin, and they are intermingled with a finer material known as the matrix, which acts as a cement. The pebbles may consist of any kind of rock, but usually they are derived from the more resistant rocks and minerals. They may be all of one kind of rock or mineral or there may be a variety of kinds. When there is one kind of rock or mineral the conglomerate is often called by that name, hence we have *quartz conglomerates, limestone conglomerates, granite conglomerates, volcanic* (lava) *conglomerates, sandstone conglomerates* etc. The pebbles may be abundant or few and scattered, in which case the rock is known as a *pebbly sandstone.* When conglomerates are composed of small pebbles they are apt to be well stratified and may show cross-bedding and other structures (see page 44) shown in sandstones etc. The cementing material of conglomerates also varies. Sometimes there is a gradation in size from the pebbles into the matrix, again there may be little gradation and the pebbles are sharply set off from the matrix, forming what is known as *pudding-stone.* The pebbles in a conglomerate may show a variety of colors. They may be all one color or the pebbles and matrix may be alike in coloring, giving one general hue to the rock. The cementing material also varies to a great extent. It may be a consolidated sand, either a pure quartz sand or

a mixture; it may be clay or of a calcareous nature or a mixture of these substances with iron oxides. The conglomerates often receive their names from the character of the matrix and we therefore have *quartz-sand conglomerates, calcareous conglomerates, argillaceous* (clayey) *conglomerates* and *ferruginous* (iron) *conglomerates.* There are a few other types of conglomerates that might be mentioned. Sometimes, through the disintegration of certain kinds of rocks as basalt among igneous rocks, boulders of disintegration or residual boulders are formed which with the sand formed through decomposition forms a conglomerate rock which is known as a *residual boulder conglomerate.* Arkose is a special kind of sandstone (page 35) which often grades into conglomerates and breccias and these are *arkose conglomerates* and *breccias.* Again pebbles of conglomerates may be worn organic structures, as coral, shells etc. and we then have *coral conglomerates, shell conglomerates* etc. *Glacial conglomerates* are produced from glacial deposits such as moraines and outwash materials where the pebbles and boulders are commonly well worn.

Conglomerates are quite common rocks, everywhere distributed in sedimentary series. They are normally deposited by swiftly moving currents of water, such as rapid rivers and estuarine currents, and are likewise formed of the coarser material, gravel or shingle, thrown by the waves toward the upper part of beaches. They are, therefore, the first deposits laid down on new sea bottoms when the sea is encroaching upon a sinking land (page 44), since a beach formation necessarily sweeps over the land at the front of the advancing sea as the initial stage to later deposits. A conglomerate or coarse sandstone is often the first or lowest member of a sedi-

mentary series and may be important in marking divisions of geologic time.

Breccias are of a similar nature to conglomerates, but the fragments corresponding to the pebbles of the latter are angular and show little or no evidence of water action. If they have been deposited by water at all there has been very little transportation and they must be close to their place of origin. As with the conglomerates the prevailing constituent gives its name to the rock, and we find *quartzite breccias, limestone breccias* etc. Breccias produced by the accumulation of fragmental material through the eruptive activity of volcanoes are known as *volcanic breccias* or volcanic agglomerates. *Talus breccias* are derived from talus accumulations and *fault breccias* from the accumulation of shattered rock fragments along a fault zone (page 30). *Glacial breccia* may be derived from glacial till, the fragments of which are generally scratched and polished. Such consolidated tills form a rock known as *tillite.* Arkosic sandstones (page 35) grade into *arkose breccias.*

Sandstones are clastic rocks composed of grains of a prevailing size between 2.5 mm and 0.05 mm. The grains may be the size of peas and the sandstones then grade into conglomerates; at the other extreme the finer-grained rocks grade into shales. Typical sandstones are those composed of quartz sand, but all rocks of an arenaceous (sandy) texture are included in this group. The grains of sandstone tend to be spheroidal and the larger they are the more perfect the rounding is apt to be. There is a very great difference among sandstones as regards the cementing material that binds the grains together. The cement may be silica, a carbonate (calcite, dolomite or siderite), argillaceous material or clay or oxides of iron

as hematite which gives a reddish color and limonite which gives a yellowish color. Some rocks are practically devoid of cement. Sandstones show a variety of colors, depending upon the nature of the cement. The common colors are brick-red to reddish brown and brown, buff to dark yellow and white to gray; green, purple and black colors occur more rarely. Iron oxides predominate where the red, brown and yellow colors are found; the cements are apt to be calcareous or argillaceous where the lighter colors are found.

Sandstones are porous rocks and they have a granular texture. When a sandstone is broken the fracture takes place chiefly in the cement leaving the grains outstanding and giving a sugary appearance and feeling to the broken surface. Sandstones have been given various names according to composition and cementing materials. Sandstones in which quartz prevails are known as *quartz sandstones* and these when pure are valuable in glass-making. In some quartz sandstones, where the cement is silica, the silica is precipitated in crystalline form around the angular grains forming *crystal sandstone*. *Quartzite* is a quartz sandstone in which the grains have been enlarged by deposition of silica until the pores are completely filled and the rock becomes a hard, very resistant mass. Quartzites are generally regarded as metamorphic rocks. *Micaceous sandstones* contain muscovite mica. *Ferruginous sandstones* are those with iron compounds as cements; *calcareous sandstones* those with carbonate of lime; *argillaceous sandstones* those in which clay is present. *Brownstone* is a sandstone with iron oxide cement much used for building purposes; the *bluestone* or *flagstone* used for flags and sidewalk curbings is a highly argillaceous sandstone of even texture and bedding; *grit*

is a coarse-grained sandstone with more or less angular particles and a silicious cement, also known as "millstone grit" because of its use for grindstones and millstones. *Arkose* is a sandstone in which there is much feldspar present and often considerable mica, and when firmly cemented bears a small resemblance to granite at a casual glance. The particles are irregular and angular. The character of the particles and the composition of the rock indicates a derivation from disintegrating granite and deposition only a short distance from the place of origin. Arkosic sandstones grade into conglomerates and breccias. *Green sandstone* is quartz sandstone or arkosic sandstone rich in glauconite grains which gives a green color to the rock, also called *glauconitic sandstone.* Rocks of this kind are sometimes very loosely consolidated, friable, and they are then known as *greensand* and *greensand-marl. Freestone* is a quartz sandstone in which the grains are loosely consolidated, commonly only bound together by pressure. This is used as a building stone. *Graywacké* is sandstone rock of prevailing gray color, an impure, highly argillaceous sandstone which is variable in composition, texture and structure. Like arkoses these rocks have quartz and feldspar; but in addition there are angular or rounded bits of various kinds of rocks — shales, slates, granites, basalts etc. — and when these pieces are larger the rocks pass into conglomerates. When the grains composing a sandstone are wholly or largely composed of carbonate of lime, as the sands around coral reefs today, the rock is known as *lime sandstone.* Such sandstones are the basis of many of the limestones of various geological formations. Wind blown sand deposits form *eolian sandstones* which are recognized by their structure and the character of the grains.

Eolian sands may be pure quartz, pure gypsum as some of the desert sands of the southwest, sometimes pure lime, such as eolian coral sands. Volcanic materials of arenaceous texture form *volcanic sandstones.* Sandstones and breccias of volcanic origin are generally included under igneous rocks.

Sandstones have a general distribution all over the world, and they are well known through their use as building stones. The red and brown sandstones, because of the insoluble nature of the iron oxide cement, make the best building stones in moist climates.

Shales, lime mudrocks etc. are *mudstones* in which the grains are less than 0.05 mm in diameter. Clay is a common constituent of such rocks but it may be entirely wanting. Quartz flours, lime flours and lime muds make up some of these rocks. Shales are formed from compacted muds and clays, have a more or less thinly laminated structure and split into thin layers. The particles in shales are too fine to be seen with the eye, sometimes with a lens. While the bulk of the material composing shales is kaolin and related substances, sometimes with white mica, tiny fragments of quartz and other minerals may also be present. With the increase of the quartz content the shales grade into sandstones. Metamorphosed shales become slates or phyllites and develop a slaty cleavage (page 56). Some shales are highly fossiliferous, and in this case they are *calcareous shales. Red shales* derive their coloring from the presence of oxide of iron. Where there is much quartz flour *silicious shales* are formed and these upon weathering break up into irregular pieces, some pencillike in form. *Pyrite shales* contain iron pyrite which upon weathering causes the splitting up of the rock. Carbonaceous material, as coaly matter and oil,

occurs, sometimes in abundance, in thin bedded shales and gives the basis for such names as *carbonaceous shales, coal shales, oil shales* and *black shales.* Certain rocks used as hones and known as *honestones* are composed for the most part or entirely of quartz flour. *Lime mudrocks* are mudrocks that have a large percentage of lime, such as the deposits being laid down today in the vicinity of coral reefs. When silica and alumina are added to these, *water limes,* our natural cement rocks, are formed.

There are all transitions between clays and shales and they are common rocks in all parts of the world. In the form of slates they are used for roofings, otherwise shales have no value for structural purposes; but they, with clays, have become of value when mixed with limestone in the manufacture of Portland cement which has largely replaced natural cement.

Limestones and *dolomites,* as has already been pointed out (page 16), are primarily of chemical or organic origin, largely the latter; and, therefore, in general, whether they contain fossils or not, are a proof of the existence of life at the time when they were originally deposited. Such deposits may be secondarily broken up mechanically and redeposited or taken into solution and precipitated elsewhere. Limestone is soluble in hydrochloric acid and may be tested for in this way. A drop of acid likewise indicates a calcareous cement in other rocks by an effervescence or bubbling. Dolomite is less soluble than limestone and sometimes the acid must be heated before any reaction can be obtained. Some limestones are very pure, consisting entirely of grains of calcite. Where there is much clay *argillaceous limestones* result; *arenaceous limestones,* when sand of a silicious

character is present. *Lithographic stone* is a very pure lime mudrock or limestone, so fine that organic remains are preserved in it with wonderful perfection. *Bituminous limestones* are dark rocks which when broken or struck give off a strong bituminous odor. When the rock is more or less filled with green grains of glauconite it is termed *glauconitic limestone.* Some limestones show a great abundance of fossils and according to their fossil content are *shell limestones, crinoidal limestones* etc. Limestones are fine-grained to very dense in texture and show a variety of colors — white, yellowish to brown, various shades of gray to black. Reddish colors are rare. Reddish and yellowish tinting or blotching is often seen on exposed surfaces where the iron carbonate constituent has become oxidized. Iron oxides give the yellow and brown colors to limestone, organic matter the gray and black colors. Limestones are generally distributed throughout the world. They are used for structural purposes, in the manufacture of quicklime, Portland cement, as a flux in smelting operations etc.

Dolomite is not an original rock, but is formed as a transition from pure limestone through the substitution of magnesia for part of the lime by waters holding magnesium salts in solution or from impure (dolomitic) limestone by solution of the lime and consequent concentration of the magnesia content. A dolomite geologically is a rock consisting dominantly of a carbonate of calcium and magnesium, but there may be an admixture of calcite (calcium carbonate). It is like limestone in appearance but is harder and if pure will react but very slowly to cold hydrochloric acid. The chemical test for magnesia is the best test. The occurrence of dolomites is much the same as for limestones. *Oölitic limestones* and

chalks have been discussed above (page 18). *Marl* is the term used for deposits of a loose, earthy or friable character which consist chiefly of an intermingling of carbonate of lime or dolomite with clay in varying proportions. Marls grade into clays and shales. The color is usually gray but the presence of organic matter or oxide of iron gives blue, black, yellow or green colors. There are *sandy marls* which are full of quartz sands with other minerals. *Shell marls* are full of shell fragments of various kinds mixed with clay. They are whitish earthy deposits. *Greensand marl* (page 35) is the name inappropriately applied to greensands.

Structures of Sedimentary Rocks

The structures to be found in sedimentary rocks may be divided into two groups. The first group includes the original surface features and original structures and the second later structures due to deformation.

Original surface features and structures. Among the *surface features* to be looked for are ripple marks, wave marks, rill marks, sun cracks, rain prints and animal tracks. *Ripple marks* may be due to waves or to currents of wind or water, the latter often known as *current marks,* and are to be looked for mostly in coarse and fine sandstones. Wave-made ripple marks are common on the beaches and are symmetrical, that is, have equal slopes on each side of the crest line. Ripple marks due to currents of water or wind are unsymmetrical, but water current, like wave-made ripple marks, have the coarser grains of sand in the troughs while the wind or eolian ripple marks have the coarser grains on the crests. Eolian ripple marks also may be formed on much steeper

slopes than those made by water. *Wave marks* are formed on the beaches today as very low, narrow, wavy ridges, the later ones cutting into those previously made during recession of the tide. In rocks they indicate the direction of the sea during deposition of the original sediments. *Rill marks* include the systems of channels formed by the backwash from waves breaking on the beach and by streams emptying over clayey and sandy flats. The channels in the former case branch and rebranch going up the beach, in the latter case going down the beach. Channels are also scoured out by water around imbedded obstructions, such as pebbles and shells, as it flows down a sandy beach. *Sun cracks* or *mud cracks* are a network of fissures formed in mud and clay deposits due to shrinking and cracking under the drying effect of the sun's rays, thus dividing the surface into polygonal areas. Material is later deposited in these cracks, and they are very well preserved in consolidated material of shallow water origin, essentially continental in origin. They are sometimes formed on tidal flats or along low, exposed lake shores, but they are most characteristic of river flood plains and playa deposits and are best developed under arid or semiarid conditions in a warm climate. *Rain prints* may also be preserved in muds, clays and fine sands and they also are particularly characteristic of continental mud deposits. *Animal tracks* in the form of foot prints or trails are to be found in rocks derived from fine-grained sediments. Tracks of animals are found along shores of lakes and the sea, but they are more apt to be the tracks of aquatic animals. Terrestrial animals leave footprints and trails in the fine clays and muds of river flood plains or playa deposits and these are among the best preserved tracks. Tracks made along a sea beach

in the sands and muds exposed by the tide are very apt to be wiped out by the incoming tides and waves.

Original structures include such features as bedding or stratification, pinching or lensing out of strata, lenses, progressive and regressive overlap, cross-bedding etc. *Stratification* of sedimentary rocks is due to the sorting power of the agent of transportation — wind or running water. The stronger the current the heavier the material carried. A slackening of current causes a deposition of finer material upon coarser and vice versa, thus giving layers or beds of different texture and also different composition where another kind of material is supplied. These beds or layers are known as *strata* (singular, stratum). Deposits have a uniform character, without stratification, if the material is deposited under uniform conditions or the material supplied is of a uniform character. Finer divisions of the strata are known as *laminae*. Under quiet conditions, which, however, permit sorting of material, very fine, even lamination is produced. Just as beds vary in texture from coarse to very fine due to changes in carrying power of the transporting agent, so there may be a variation from coarse below to fine above in thin, uniform laminae deposited in quiet water, since even under the quietest conditions the larger grains tend to settle out first.

The dip of rock strata will be discussed under the sections on folding and other deformation. There is, however, a *primary dip* or *original dip* to be found in rock layers. When sediments are deposited the strata assume the attitude or slope of the underlying surface. This is the primary dip, which is measured by the vertical angle between this slope and the horizontal.

The interval between any two beds in a sedimentary

series, measured perpendicular to the bedding, is known as the *stratigraphic interval.* This interval, however, varies as beds or strata thicken or thin in various directions due to different conditions of deposition. Sometimes a stratum continues to thin out in a certain direction until it disappears altogether and the beds immediately above and below come in contact. This is known as *pinching* or *lensing out of strata* (figure 2). This is

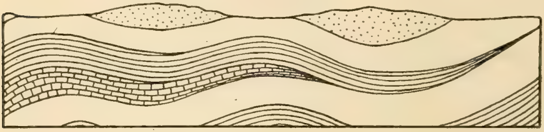


Figure 2 Cross section illustrating pinching or lensing out of strata

why a layer or bed of rock in a certain region may be present in one locality but not in another. Small lenses are to be looked for in rock strata. Hollows or channels in gravel deposits may be filled with sand. This, in coarse rocks, forms lenticular beds of sandstone which thin out laterally. Some lenses of this kind are due to buried sand bars. The reverse is also found where a stronger current has deposited gravel in a channel scoured out of sand. Strata vary laterally in texture and porosity as well as in thickness of the bed. Sandstones may become finer and grade laterally into shales, and so on. The *porosity* of a rock is the proportion of pore space to the entire volume of the rock and is measured by the amount of water a stated volume of rock will contain. If the spaces between the grains of a sandstone gradually are filled laterally with an increasing amount of cement or more and more fine clayey material the porosity of the rock is gradually less-

ened. The porosity of a rock depends largely upon the size of the composing fragments.

When *fossils* occur in stratified rocks, if the animals were free-living and unattached, as in the majority of cases, they are found lying parallel with the bedding. Attached animals are preserved as attached, in some cases to older rock, which is readily distinguished; and plants, such as the trees of the Coal Measures, may often be buried and preserved *in situ,* that is, in the position in which they grew. *Pebbles* in stratified rocks, if they are few and scattered in a large amount of finer material such as sand, lie flat in the beds whether of beach or river origin. When pebbles are present in large quantities in

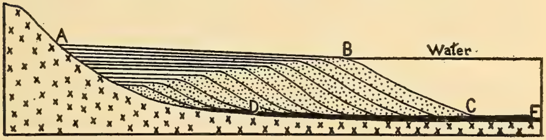


Figure 3 Delta structure: *AB* topsets; *BC* foresets; *DE* bottomsets.

deposits they assume a position which gives the least resistance to the force of waves or current. On beaches they are often found standing vertically, and in river deposits they are seen imbricating or overlapping one another down stream, and are so found in rocks derived from such deposits. Strata which have not been folded or deformed in any way show the effect of compression from the weight of the overlying deposits when there has been long-continued sedimentation in a region. The sedimentary material becomes more compact. Inclusions such as pebbles and fossils give proof of such compres-

sion. Fossils are flattened out and in the case of pebbles the thin layers or laminae are bent about the inclusions.

Cross-bedding or *false bedding* is another type of original structure found in stratified rocks and is seen to best advantage in delta deposits (figure 3). In this structure certain laminae of the deposits lie in a position which is oblique to the main stratification. A delta which has been formed through deposition in standing water shows three types of beds in its structure — bottomsets, topsets and foresets. *Bottomsets* are formed of the finer materials that wash out and settle on the floor of the body of water in which the sediments are being deposited. They are nearly horizontal in position. The *topsets* are formed of the material washed over the upper surface of the delta deposit. These layers have a primary dip which is the same as the slope of the subaerial surface of the delta. The *foresets* are composed of the materials carried over the front of the delta into the water. They are oblique to both the topsets and bottomsets and their primary angle of dip is the angle of repose of materials under water, that is, the angle at which the sediments can come to rest and hold their position. Cross-bedding may also be found in sand bars in rivers, in sand reefs, in current deposits in the sea, in torrential deposits and in eolian or wind deposits such as sand dunes.

As has been pointed out above, in marine deposits the coarser deposits are near the shore and the material grows finer and finer as one approaches deep water. If the land is sinking the sea encroaches upon it, depositing the coarse beach sediments upon what was previously a land erosion surface. Deep waters replace shallow waters. The fine muds of the deep waters are laid down upon the sands of previous shallow waters and limy muds or oozes of

the deepest waters are deposited in the previous zone of mud deposition. If subsidence goes on, the sea extends farther inland and the progressive succession of fine deposits upon coarser continues. This relation of the different beds is known as *progressive overlap* (figure 4) and this particular type as *marine transgressive overlap* (Latin *transgressus,* a passing over or across). If the

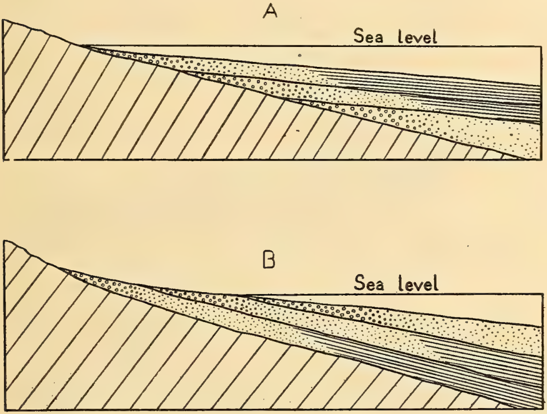


Figure 4 *A* Marine transgressive overlap: finer beds deposited upon coarser. *B* Marine regressive overlap: coarser beds deposited upon finer.

land is rising instead of sinking the process is reversed, the sea retreats from the land, shallow waters take the place of deeper waters and coarser sediments are deposited upon finer materials. This is known as *marine regressive overlap* (Latin *regressus,* a going back or return). Overlap may be *marine* or *nonmarine.* In marine deposits progressive overlap is toward the source of sup-

ply, that is, toward the land. In continental deposits progressive overlap is away from the source of supply, as exemplified in lake and alluvial cone deposits. Streams constantly deposit sediments in lakes and tend to fill them up; the lake floor muds are gradually covered with the coarser sediments brought by the streams producing a *lake regressive overlap,* the normal lake succession. In an *alluvial cone* each successive bed spreads out and extends beyond the one previously deposited forming a *transgressive overlap* (figure 5).

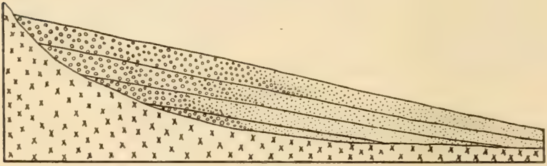


Figure 5 Alluvial cone transgressive overlap

The structures in sedimentary rocks may be interpreted by the trained observer. They indicate the conditions under which the sediments composing the rocks were deposited and their origin. In residual deposits, or where the sediments have been transported only a short distance, the nature of the parent rock is indicated. When there has been long transportation and wear it is more difficult, and sometimes impossible, to determine this. Some sandstones from their composition might have been derived from igneous or metamorphic rocks. Rocks show whether there has been current action, as is usually the case in wind and river deposits, or quiet deposition. Ripple marks, rill marks, cross-bedding, lenses etc. characterize the

former; fine lamination or lack of bedding the latter. The texture of the materials indicates the strength of currents and the direction is shown by inclusions, such as fossils and pebbles, and by such structures as cross-bedding, ripple marks, rill marks, wave marks etc. In lake and marine deposits coarse sediments indicate shallow water deposits; finer sediments deep water deposits. The character of the fossils also helps out here. Marine limestone deposits very often are deep-water deposits, but more than this they indicate clear water conditions. Continental deposits may be distinguished from marine and littoral deposits. When fossils are present they are distinction enough. Aside from this, marine deposits show less variation in character, have comparatively uniform bedding and may be of enormous thickness. In more shallow water they may show ripple marks, but mud cracks, rain prints etc., so characteristic of tidal areas and flood plains of rivers, are not to be found. Littoral deposits are never of great thickness. Their fossils, when present, are characteristic. They have, in common with continental deposits, ripple marks, rill marks, rain prints, suncracks, tracks and trails etc., but these structures are more apt to be found in muds of continental origin. Littoral deposits consist chiefly of sandstones with associated conglomerates and mudstones. Continental deposits may contain fresh-water, brackish water or land fossils, never marine. Some of these deposits attain great thickness. Wind and glacial deposits are very characteristic, and also delta deposits, which when laid down in the sea show a mixture of continental, littoral and marine deposits. The finer continental deposits may show sun cracks, rain prints, foot

prints of land animals, ripple marks, cross-bedding etc. Lime rocks that show sun cracks are of continental origin, but they are rare. Sediments laid down in lakes or the sea are well-stratified; river deposits and deposits formed by glacial streams are poorly stratified. Wind-blown dust shows little or no stratification, but wind-blown sand is well stratified and shows cross-bedding and ripple marks. Residual deposits, glacial deposits and material transported only a short distance are composed of angular fragments. Water-deposited material is rounded to a greater or less degree depending upon the amount of transportation and wear and rapidity of deposition. Eolian deposits of sand have well-rounded grains.

Climate and physiographic conditions at the time of deposition may also be evident from structures in the rock. Mud cracks, foot prints etc. have their best preservation under semiarid conditions. Interbedded gypsum, salt etc. indicate the same thing. Red color in rock may be due to deposition under arid conditions, but red color is also found in deposits of warm, humid climates due to the dehydration of ferric hydrates. Glacial deposits, of course, indicate a cold climate; arkosic sandstones a relatively dry climate. Desert conditions are indicated where thick beds of eolian sandstones are found; and where sands are coated with a red oxide of iron they are of desert origin. Coal beds indicate a marsh condition and a warm or cool, moist climate. Where there is a large percentage of kaolin in deposits the area which was the source of the muds must have been undergoing warm, moist conditions which favor decomposition. In an arid or semiarid climate deposits have a large

percentage of soluble mineral constitutents; also in a cool climate where formed by glacial scouring. Where lake or, especially, marine beds lack fossils there is evidence of lack of suitable conditions of life—too great salinity, turbid waters, too great cold etc. When fossils are dwarfed there are likewise poor life conditions. Thick deposits of gravels and sands such as alluvial cone deposits indicate that mountainous country is near-by. On the other hand, clays formed by long and thorough decomposition indicate areas of low relief as well as a moist, warm or temperate climate; while coal beds, as pointed out above, indicate swamps and marshes.

Figure 6 Outcrop of rock illustrating strike and dip (after Jas. Geikie)

Structures due to deformation. Sedimentary rocks from the time they are deposited are subjected to deforming forces acting within the earth's crust which disturb the original arrangement of the material of the rock and modify the original structures. Deformation structures, therefore, are secondary, and include folding and warping, faulting, development of joints and slaty cleavage.

Horizontal strata are the exception rather than the rule and with or without accompanying folding we find *inclined strata.* The direction in which the beds incline is the direction of dip or maximum angle of slope of the surface; the direction in which the edges of the beds extend, that is, the intersection of the inclined strata with a horizontal surface, is the *strike,* and this is at right angles to the dip (figure 6). The direction of dip and strike is obtained with a compass. The *angle of dip,* the angle of inclination from the horizontal, is measured by

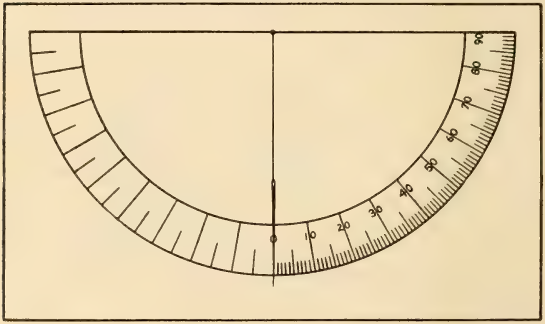


Figure 7 Diagram illustrating a homemade clinometer with needle attached as pointer

an instrument known as a *clinometer* (Greek *klino,* to incline; *metron,* measure). The lower edge is held parallel to the dip of the strata and the pointer, which swings free, indicates the number of degrees the beds are dipping. A simple clinometer may be made at home with a piece of cardboard or wood, a small weight or needle and thread (figure 7). The board or cardboard should have parallel sides. Fasten to it a semicircle of paper or metal

with the ends of the semicircle on a line parallel to the upper and lower edges. At the center of this line fasten a thread by a pin or in some other way and attach at the other end a small weight so that it hangs below the arc but above the edge of the board or cardboard. The thread then should cut the graduated semicircle exactly in the middle, which is zero. Each end of the semicircle is marked 90° and the arc on each side of the zero point is then marked off into the correct number of spaces, ten degree spaces first, then five, then one. If preferred one space may be used for every two degrees. A needle may be attached to the thread instead of a weight and used as a pointer. The width of the outcrop or exposure of rock at the surface depends upon the angle at which the strata are dipping. When they are vertical the edges of the strata are exposed and the width of the outcrop will be the thickness of the beds. The more nearly horizontal the strata are the greater the width of the outcrop on a horizontal surface. A trained geologist can calculate the thickness of a bed of rock when he has the angle of dip and the width of the outcrop.

There are three principal kinds of *folds*: anticlines, synclines and monoclines (figure 8). An *anticline* is an arched fold or upfold, opening downward. The sides of the folds are the limbs and the crest line the axis of folding. A *syncline* is a trough fold or downward fold, opening upward. Sometimes in nearly horizontal or gently dipping strata the dip changes from gentle to steep and back again, giving a steplike bend in the strata. This is known as a *monocline*. The axis of an anticline or syncline may extend in a horizontal position for some distance and then dip into the ground and die away. This dip of the anticline or syncline is known as the pitch, and

they are referred to as *pitching anticlines* and *pitching synclines.* There are a variety of anticlines. They are symmetrical, asymmetrical, overturned, recumbent, fan-shaped etc. A *symmetrical anticline* has both arms or limbs dipping at the same angle; in an *asymmetrical anti-*

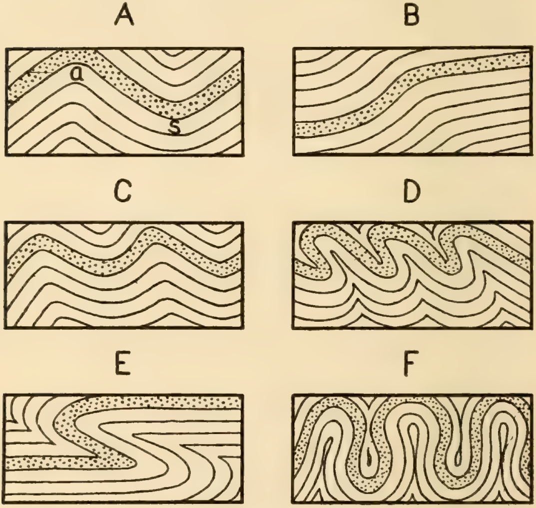


Figure 8 Folds. *A* Symmetrical anticline, *a*, and syncline, *s*. *B* Monocline. *C* Asymmetrical anticline. *D* Overturned anticlines. *E* Recumbent anticline. *F* Fan folds.

cline one limb has a steeper dip. In strongly folded areas folding is sometimes so strongly developed that one limb lies under the other and the beds are in a reversed order forming an *overturned anticline.* When this overturning is continued so far that the limbs lie in a practically hori-

zontal position a *recumbent anticline* is developed. *Fan-shaped folds* are formed when in anticlines the lower part of the limbs are pinched together or compressed and the upper part bulges beyond on both sides. An anticline with short axes is known as a *dome fold* or *dome.* The longitudinal and transverse axes may be about equal or the longitudinal axis may be many times longer. There are similar varieties of synclines. A syncline corresponding to a dome is known as a *basin fold* or *structural basin. Isoclinal anticlines* and *synclines* are formed when there is close regular folding in which the limbs of all the folds have practically the same inclination. It can be readily understood that erosion in folded regions will bring to light very complicated structures. There will be repetition of beds, reversal of beds etc.; the more complicated the folding, the more complicated the surface structures will be. Folds may be simple or complex. A mountain region may be composed of a series of anticlines which together form a large arch. Such a compound anticlinal series is known as an *anticlinorium.* A similar compound synclinal series is known as a *synclinorium.*

The earth's crust is traversed in all directions by fractures, and they are found in all classes of rocks. These fractures are known as *rifts* or *fissures* when they are large and traverse many adjoining rock masses for great distances. When they are smaller in size and confined to a single rock mass or set of strata they are known as *joints.* Joints are present in the rocks in systems, that is, they run as divisional planes or surfaces in definite directions more or less parallel one to the other. There may be two directions of jointing, or three or even more, and they divide the strata into closely fitting blocks. Finer-grained rocks such as shales and limestones show more perfect jointing.

Faults are fracture planes in the earth's crust along which there has been displacement of strata (figure 9). The surface along which movement takes place is the *fault-plane* or *fault-surface.* When there are a series of faults together, each showing a small amount of slipping in the same direction the faults are known as *step-faults* and the region covered by the entire series as the *fault zone.* The surface along which movement takes place is polished, striated and grooved. The term *slickensides* is used for such surfaces. The intersection of the fault-plane with a horizontal plane or surface gives the *fault-line* and its direction is known as the *trend* (sometimes strike). The dip of the fault-plane, that is its departure from the vertical, is known as the *hade.* The term dip is restricted to inclined strata. Where there is an inclined fault-plane or surface the side projecting below is called the *foot wall,* the overhanging side the *hanging wall.* The vertical distance between the same strata on each side of the fault-plane is the amount of *vertical displacement* or *throw.* The amount of displacement in a horizontal plane is known as the *heave.* There is no heave when the fault-plane is vertical. In faulting there may be movement on both sides of the fault-plane or one side may be stationary and the other side may move up or down. There are two main kinds of faults, normal and reverse. In a *normal fault* the hanging wall or overhanging side slips down with reference to an assumed stationary foot wall. This is also known as a *gravity fault.* In a *reverse fault* the hanging wall moves up. Reverse faults are found most frequently in regions where much crushing and folding has taken place. When the fault-plane is gently inclined to nearly horizontal such faults become *thrust faults,* which are sometimes of great magnitude involving regions

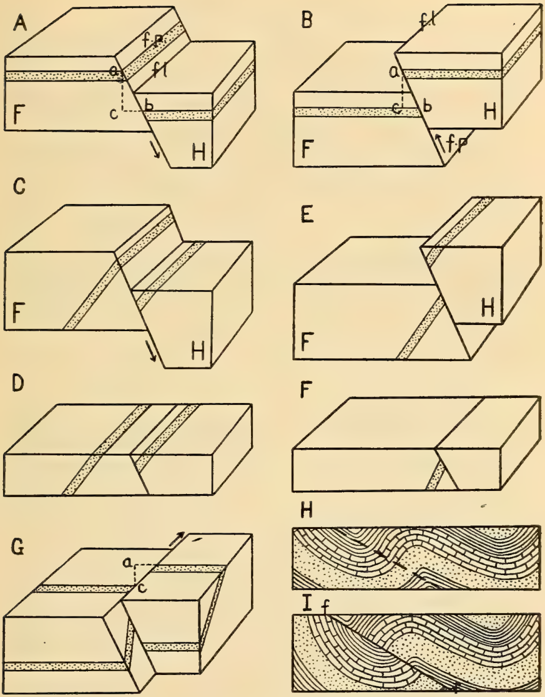


Figure 9 Faults. *A* Normal fault; *F* foot wall; *H* hanging wall; *f.l.* fault line; *f.p.* fault plane or surface; *bac* the hade; *ac* vertical displacement or throw; *bc* horizontal displacement or heave. Arrow shows direction of movement. *B* Reverse fault. *C* Strike fault (normal) with slip along the dip. *D* The same after erosion, showing repetition of strata. *E* Strike fault (reverse) with slip along dip. *F* The same after erosion, showing omission of strata. *G* Horizontal fault (dip fault with strike slip): *ac* horizontal displacement or heave. *H*,*I*, Thrust fault: *H* section of folded area with position of thrust plane indicated by dotted line; *I* area after thrusting showing older beds resting upon younger; *ff* thrust fault line.

of enormous area. The fault-plane is then known as a *thrust plane.* If faulting is more rapid than erosion an initial cliff or *fault scarp* is formed. If erosion keeps pace with faulting there will be no fault scarp except as one may be exposed by later erosion along the fault line. The motion along a fault-plane is not necessarily vertical and according to the kind of movement *horizontal, oblique* and *rotary faults* are developed. In a horizontal fault the amount of movement along its strike is called the *shove* or *strike slip,* and if the fault cuts across the bedding this can be measured. More than one movement is probably involved in most faultings. When the fault-plane is parallel to the strike of the strata in tilted rocks the fault is termed a *strike fault.* In a *dip fault* the fault-plane is at right angles to the strike of the strata; in an *oblique fault* at an angle of about 45°. Through faulting and subsequent erosion certain strata of rock in a region may be eliminated; again there may be a duplication of beds or the strata may not be continuous on opposite sides of the fault etc. In thrusting there is a duplication of beds and also an inversion of order, formations of older age coming to rest upon younger beds. There are great overthrusts involving whole regions and where the fault-plane is nearly horizontal they are difficult to recognize except by the repetition of strata and relative ages of the beds involved. Certain features accompany faultings, such as slickensides, crumplings, fault breccias etc.

Slaty cleavage is another structure produced in finer-grained stratified rocks. When such rocks are subjected to intense squeezing there is a flattening and expansion of particles at right angles to the compression, resulting in the development of a secondary parallel structure in the rock which has no relation to

original structures, as bedding planes, etc. The rock is split through erosion into thin plates or may be so split artificially. This is slaty cleavage. Our common roofing slates are produced in this way. Slaty cleavage is most commonly found in clay mudrocks. Color bands or fossils, if present, show the original bedding planes.

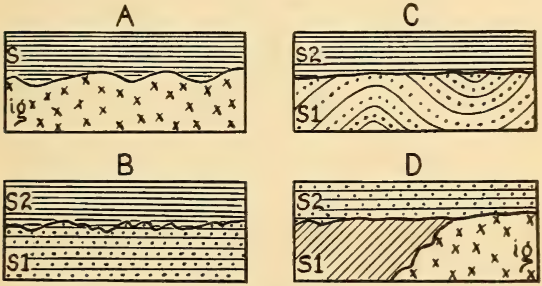


Figure 10 Unconformities. *A* Unconformity between igneous, *ig*, and sedimentary rocks, *s*. *B* Parallel unconformity, or disconformity, between two sedimentary series, *s1*, *s2*. *C* Angular unconformity or nonconformity between two sedimentary series. *D* Unconformity between igneous rock, *ig*, and two sedimentary series; angular unconformity between the two sedimentary series, *s1*, *s2*.

Unconformities and disconformities. Unconformities and disconformities properly belong with original structures, but they are better understood if they are treated after a discussion of tilting and folding (figure 10). Where strata have been deposited in uninterrupted succession, have roughly parallel bedding planes and have been similarly affected by movements they are said to be *conformable*. Such a series of beds

may be found resting upon a lower series with beds dipping at another angle and with an erosion surface in between. This is known as an *unconformity,* and is brought about as follows. The lower beds were deposited in a more or less horizontal position under water and later were uplifted, tilted or folded to form a land surface. Erosion took place over this land truncating the folded and tilted beds and tending to reduce the area to a low surface. Later the eroded land surface was depressed beneath the water and a new series of strata was deposited upon the truncated edges of the older series of beds. This condition in which one series of strata rests upon the upturned edges of another series is sometimes termed *angular unconformity* or *nonconformity.* An unconformity may also be developed by the deposition of sedimentary rocks upon an eroded surface of igneous or metamorphic rocks. We may find two apparently conformable series of rocks with an erosion surface between. Such a condition may be produced by the advance of the sea over the eroded surface of a formation which has not been subjected to tilting or folding, and deposition of a new series of strata. This condition is known as *parallel unconformity* or *disconformity.* In disconformities the erosion line may be clearly visible or not evident. When visible it may be evident through the inclusion of pebbles of the older rock in the base of the lower bed of the new series. Sometimes in the case of marine formations there may be an old soil bed or eolian sands between the two formations. When the erosion line is not visible the disconformity is only indicated by the difference in age of the two formations which are recognized by the fos-

sils and comparison with the known succession of the series elsewhere.

Unconformities and disconformities may be of large extent or *regional* or of small extent or *local.* A *regional unconformity* may be recognized, as pointed out above, by discordance in bedding at the line of contact. There are, however, other distinguishing characters to be looked for, such as the presence of a basal conglomerate or arkose at the contact line; faults, dikes and other igneous intrusive bodies in the lower series that are truncated by the upper series of beds; greater amount of folding or metamorphism in one formation than in the other, etc. The number of geologic formations missing in an unconformity or disconformity constitutes its *hiatus.* One must be careful not to confuse cross-bedding with angular unconformity, nor contemporaneous erosion with disconformity. Sometimes after sedimentation has been going on for some time a change in conditions causes erosion to take place. The deposition of the sediments may begin again after a relatively short time and a break or unconformity is developed of so small an extent that it is only a local unconformity. As the erosion, however, took place in unconsolidated sediments during a short cessation of deposition it is referred to as *contemporaneous erosion.*

Age Relations of Sedimentary Rocks

The beds of sedimentary deposits are built up layer by layer. Therefore, each succeeding stratum is younger than the one just below and older than the one deposited next above. This is true likewise for the consolidated strata in most cases, but when there

has been severe deformation in any region the order of the strata may be reversed as has been shown in the section on folding. To the original and normal sequence of strata from older to younger the term *stratigraphic sequence* is applied.

The relation of a bed of rock to the one above or the one below is known as its *relative age*. When the normal relation is altered fossils, when present, and comparison with the same series elsewhere will determine the relative age. The age of a rock bed may also be considered from the point of view of the place it holds in the geologic time scale or its *geologic age*, or from the point of view of its *actual age in years*. Geologists all over the world have come to more or less agreement upon a *time scale*, which is a definite succession of rock formations for the whole world, and to these divisions names have been given (page 190). Just as human history can be divided, so geologic history may be divided into eras, periods etc., and the different kinds of rocks and rock structures can be referred to their respective geologic periods. The student will find some variation in the usage of different writers, especially in the minor divisions. The various divisions have been named with no particular system. The name may be derived from some place or locality as Jurassic period from the Jura mountains, Devonian period from Devonshire in England where the rocks were first studied, and Onondaga limestone from Onondaga county. The carbon, that is coal, content of another system of rocks has given to them the name Carboniferous (carbon-bearing); and the Cretaceous was named from the chalk rocks (Latin *creta*) prevalent in that period. Besides the scale of time, there is

also a *rock scale,* and the International Geological Congress has adopted the following divisions of the two scales:

Time Scale	*Rock Scale*
Era	Group
Period	System
Epoch	Series
Age	Stage
	Substage
	Zone

In the rock scale the divisions are carried farther because of the generally local character of the minor divisions. To illustrate these two scales we have the Paleozoic Era of time in which the Paleozoic Group of rocks was laid down; the Devonian System of rocks was deposited in the Devonian Period; the Erian Series (Hamilton-Marcellus beds) in the Erian Epoch; and the Hamilton Stage comprises the rocks of Hamilton Age. The geologic age of rocks is much harder to determine than their relative age. Fossils must be identified, and when no fossils are present the ages of beds can be determined only by correlation with other beds of which the geologic age has been established. There is no region where the strata of even a majority of the rock systems of the earth are represented. Data are gathered from various places and are finally put together in their true order to make a complete and accurate record. Unconformities occur which may represent a loss of one or more systems of rocks, but the beds in two different sections may complement each other. What is missing in one section may be present in the second and a complete section thus gained. Beds are overturned or faulted and older beds rest upon younger ones; a stratum of rock may,

through erosion, be represented only by isolated patches miles apart. Sometimes a bed of rock varies greatly even in a short distance in its lithological character, that is, in the mineral composition and texture as well as in external appearance. These are some of the difficulties that face the geologist, but in all these cases fossils when present are usually a key to definite knowledge of the age of the strata.

The actual age of rocks expressed in thousands, hundreds of thousands or millions of years can be computed only approximately and then the results are likely to be far off. Computations have been made by geologists and physicists; the former through a study of rates of erosion and deposition of rocks, the latter through a study of radioactive substances. Throughout the years the estimates of the geologists for the age of the earth have varied from around 40,000,000 years to the present reckoning of at least 500,000,000 years since the beginning of the Precambrian. The most recent reckoning of the physicists gives nearly a billion and a half years from Precambrian times, and this is probably a more nearly correct estimate. The geologist is more concerned with the relative and geologic ages of the rocks than the actual age, and for the paleontologist the outstanding fact is that there has been unlimited time for the development of life.

Igneous Rocks

Igneous rocks are formed by the cooling of molten rock. Molten rock that reaches the surface is known as lava; when it does not reach the surface, as molten magma. Rocks derived from molten material that reaches the surface of the earth on land or below water

either in a volcanic eruption or through large fissures in the earth's crust are known as *extrusive igneous rocks* or *lava rocks;* those derived from molten material that does not reach the surface but cools within the crust of the earth are known as *intrusive igneous rocks.* In certain intrusive forms of rocks the magma has cooled essentially where formed. They enlarge downward and no base has ever been found. These are the *deep-seated* or *abyssal rocks,* also termed *subjacent.* The older rock into which molten rock is intruded is termed the *country rock* and sometimes blocks of this country rock are found included in the igneous rocks. These are known as *inclusions.* The surfaces bounding the igneous rock are contacts and the zone is known as the *contact zone.* Because changes are brought about both in the country rock and the igneous rock in the contact zone, that is, metamorphism has taken place, the contact zone is also known as the *contact metamorphism zone.*

Intrusive igneous rocks occur as intrusive sheets or sills, interformational sheets, laccoliths, dikes, necks, batholiths, stocks and bosses (figure 11); among extrusive igneous occurrences are necks, flows and cones. An *intrusive sheet* or *sill* is formed by igneous material that has been forced upward into sedimentary rocks and has spread out in a layer between and along the beds of a series of sedimentary rocks. They may vary from a foot or less to several hundred feet in thickness. The rock forming the Palisades of the Hudson river is an intrusive sheet. When the layer of igneous material is intruded along a surface of unconformity it is termed an *interformational sheet.* *Laccoliths* are like sills, but they are thicker in comparison to their width, giving lenticular shaped masses of igneous rock between stratified beds,

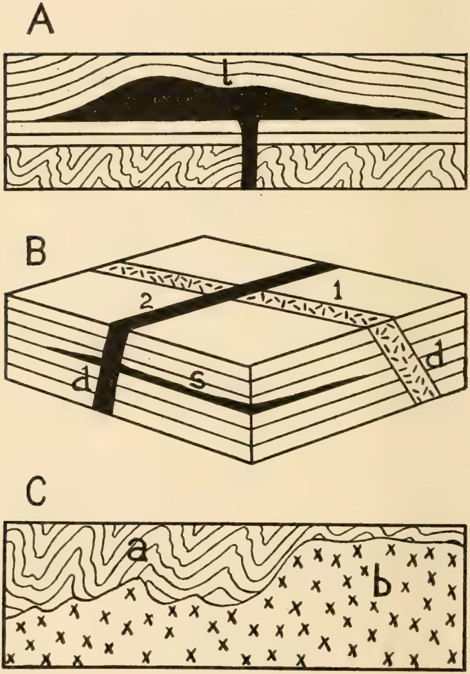


Figure 11 Dike, sill, laccolith, batholith. *A* Laccolith, *l*, with feeding neck. *B* Dikes, *d*, and sill, *s*. Dike 2, shown at surface cutting across dike 1, is younger. *C* Batholith, *b*, thrust into country rock, *a*.

with distinctly arched roof. They, too, may be interformational. Sheets and laccoliths are usually concordant with the bedding, but they may break across the bedding locally. *Dikes* are sheets of igneous material not concordant with the bedding, and are the result of the simple filling of fissures in rock masses by molten magma from below. They not only cut across the stratification planes of sedimentary rocks but also pass through other igneous rocks or metamorphic rocks. Dikes may vary from a fraction of an inch to half a mile or so in thickness, and an individual dike may thin out or pinch and swell along its length. An intrusive mass, nearly cylindrical, with vertical or steeply inclined axis, is called a *neck*. *Batholith* is the term applied to those huge irregular masses of igneous rock that have no base and are discordant in their relations with the rocks they invade. They are the deep-seated or abyssal rocks, exposed by erosion, which are found in the oldest areas of the earth's crust, such as our Adirondack mountains. A small batholith is termed a *stock,* which becomes a *boss* if it has a circular ground plan. Stocks and bosses may be only upward extensions of concealed batholiths. A batholith may be exposed over thousands of square miles and is arbitrarily considered as covering more than 40 square miles. In extrusive rocks the extrusion may be a quiet flow or explosive. The quiet extrusions may be *fissure eruptions* in which the molten rock rises to the surface and pours out as a flow of *lava,* forming an *extrusive sheet,* or *central eruptions* in which the outflow is from a tubular opening or pipe. In the former, the solidification of material in the fissure, when outflow has ceased, forms a dike or sill, according to its relations; in the latter a *volcanic neck* is formed, such as Stark's

Knob, north of Schuylerville, N. Y. Volcanic necks vary from a few feet to a mile in diameter. In a volcano quiet flows may alternate with explosive eruptions, and a *volcanic cone* may be built up entirely of lava, entirely of ashes or cinders or both. Due to expansion of vapors, chiefly steam, eruptive volcanic material has a more or less pronounced vesicular structure. In an explosive eruption the material projected varies from the finest dust to pieces weighing several hundred pounds. Deposits of the finer material form *volcanic tuffs;* of the coarser material, *volcanic breccias.*

The texture of igneous rocks depends upon the rate of cooling, the kind of magma, the place of cooling and also the bulk of the magma. The more slowly a magma cools the more opportunity there is for growth of the mineral crystals, and we have everything from a comparatively slowly cooled rock that is a mass of crystals (*holocrystalline*), as granite, to rapidly cooled rocks in which there are no crystals (*glassy*), as obsidian. A rock that is crystalline but in which the grains are too fine to be visible to the eye is *dense.* The texture of a rock may be uniform, that is, the crystals of each mineral are of about uniform size. Such rocks are termed *granitic* or *granular* and may be coarse-grained or fine-grained. Sometimes there are large crystals scattered through a fine-grained or glassy ground mass. Such a rock is *porphyritic.* Rocks according to their composition are acidic or basic. Basic magmas are more fluid and tend to form coarse crystals, therefore producing coarser-grained rocks. Finer textures tend to develop more frequently from acidic magmas. Glassy textures are common here and less frequently developed from basic magmas. The power of forming crystals is increased by the presence

of gases and water vapor, which are known as *mineralizers.* Rock of very coarse texture is formed, especially in fissures along which the gases and vapors escape. They are known as *pegmatite dikes* or *veins* from the name given to intergrown masses of quartz, feldspar and mica found where they occur in granite. The more deeply buried the magma, the more slowly will it cool and hence the more coarsely crystalline the resulting rocks. The central part of a magma cools more slowly than the outer part, and a large mass cools more slowly than a small one. In the case of porphyries the large crystals developed while the ground mass, which indicates rapid cooling, was still fluid.

Magmas and hence the rocks composing them are made up predominantly of eight oxides: *silica* (SiO_2); *alumina* (Al_2O_3); *iron oxides* (*ferric,* Fe_2O_3; *ferrous,* FeO); *magnesia* (MgO); *lime* (CaO); *soda* (Na_2O) and *potash* (K_2O). Chief among these oxides is silica which upon solidification of the magma unites with the other oxides to form various silicate minerals. Magmas vary from a composition in which silica is most abundant (sometimes 75 per cent of the mass), with alumina and potash next, to a composition which shows an increase in the oxides of sodium, calcium, magnesium and iron and a decrease in silica (50 per cent or less) together with a reduction in the oxides of potassium and aluminum. The former are termed the *acid magmas* and from the acid portion of an igneous magma are formed rocks in which light-weight and light-colored minerals predominate; the latter are termed the *basic magmas* and from the basic portion of an igneous magma are derived dark-colored and heavy minerals.

The more important minerals composing igneous rocks are quartz, the feldspars, the micas and the ferromagnesian group. *Quartz* or silica is glassy in appearance and rarely in crystals and can be recognized by its hardness. It will scratch glass but can not be scratched by a knife. The *feldspars* are silicates of aluminum and an alkali metal (as sodium and potassium) or an alkaline earth (as calcium and magnesium) or both. The feldspars may be roughly divided into *orthoclase* or *potash feldspar* and *plagioclase feldspars* or those with soda or lime or both. The feldspars with potash only are the most acid; with lime only, the most basic. Potash and potash-soda feldspars are characteristic of acid rocks, or rocks high in silica; and in color are very apt to show some tinge of red, varying from pale flesh color to strong brick-red or brownish red, a distinct flesh color being most common. The lime and soda-lime feldspars are found in basic rocks and are commonly of a gray color — dark smoky or bluish gray or even black. Feldspar will scratch glass, can not be scratched by a knife and can be scratched by quartz. The micas for general purposes may be divided into light-colored or *muscovite* micas and dark-colored or *biotite* micas. Muscovite mica, the common, light mica, is a silicate of potassium and aluminium with some hydrogen and is found in acidic rocks where other potash minerals are found, as granites, and in metamorphic schists. Biotite or black mica has in addition magnesium and iron with a reduction of silica and aluminum, which makes it a more basic mineral. In the mica-ferromagnesium series, muscovite is placed at the acid end and magnetite (pure iron oxide) at the basic end, and between in

order are biotite mica, hornblendes, pyroxenes and olivine. Biotite and hornblendes indicate basic rocks, pyroxenes greater basicity, and only the most basic igneous rocks have olivine. Free quartz is usually not present when there is pyroxene and olivine. Though some of the hornblendes are white to gray in color, they usually vary from gray-green through bright greens to darker greens and black. Pyroxenes have about the same colors and olivine varies from olive-green to yellow-green. The beginner can not hope to distinguish the hornblendes, pyroxenes and olivine, but usually the lack of free quartz will be an indication of the more basic pyroxene and olivine. When minerals crystallize from molten magma the more basic minerals crystallize out first and quartz, if there is any silica left over uncombined, separates out last and fills the spaces between the other minerals, hence its irregular form. Thus the order of crystallization in igneous rocks is ores or oxides of iron (as magnetite), ferromagnesian minerals (as pyroxenes, hornblendes etc.), soda-lime feldspars, potash or potash-soda feldspars, quartz. The minerals first developed have more regular forms, because they have more room in which to crystallize.

Granite occurs in the rock group which contains the most acidic of the common igneous rocks. It is a granular rock, the coarse-grained forms of which are composed almost entirely of orthoclase feldspar and quartz. Generally two kinds of feldspar are present, orthoclase and acid plagioclase, and they may as a general rule be distinguished by their color. Often muscovite mica, biotite mica and hornblende are present and recognizable by their dark colors. Mica is very soft and scaly with a high

luster. With a reduction in quartz the rock approaches *syenite,* which consists typically of orthoclase feldspar and hornblende, and when there is an increase in acid plagioclase feldspar, quartz diorites or diorites are approached. *Quartz diorite* resembles granite but is darker and heavier. *Diorites* differ from the above in having no quartz. A granite in which feldspar crystals are of large size and distinct, standing out against the finer granular background, is called *porphyritic granite.* Pegmatite dikes are so common in granite that, unless otherwise specified, whenever the term is used granite is meant. *Pegmatite* is a very coarse variety of granite occuring in veins of dikelike masses. The chief minerals are quartz, feldspar (usually orthoclase) and muscovite mica. The crystals are sometimes a foot or more in diameter and it is from this source that mica for commercial purposes is obtained. The quartz and feldspar are sometimes so intergrown that upon the feldspar surfaces the quartz appears as dark irregular masses resembling Arabic writing. This is known as *graphic granite.*

The basic igneous rocks are all included in the gabbro-basalt group. *Gabbro* is a coarsely granular dark rock chiefly composed of basic plagioclase feldspar and pyroxenes, though hornblende, olivine and biotite may be present in certain varieties. With a decrease in the feldspar and an increase in the ferromagnesian minerals the gabbros pass over into other rocks, pyroxenites etc. *Basalt* is the name given to the fine-grained or dense basic igneous rocks derived from surface flows. *Diabase* is a fine-grained, wholly crystalline rock which stands between the gabbros and basalts. It is common as an intrusive rock in dikes or sills. In the field the name *dolerite* is applied to dark rocks which may be either gabbros or diorites

when it is not possible to determine the dark mineral. *Trap* is the term used for dark dense basalts or diabases. Weathering sometimes gives a greenish cast to old trap or basalt rocks, and they are then referred to as *greenstones.*

Structures in igneous rocks. Certain structures are to be looked for in igneous rocks besides changes such as marginal variation in composition which takes place in both the igneous and country rock along the contact zone. Inclusions of the country rock have already been mentioned; also the development of *porphyritic structure* and *pegmatite dikes.* Among other structures to be looked for are vesicular and amygdaloidal structures, miarolitic cavities, jointing and columnar structure. *Vesicular structure* is common in extrusive sheets and may sometimes be found in rocks intruded under pressure. It is due to the escape of water and other vapors from the soft, but stiffening, molten material, rendering it spongy. This happens particularly in the dark basaltic lavas. These cavities, especially the smaller ones, later become filled with various minerals, quartz, calcite etc., and this is termed *amygdaloidal structure* from the Greek word for almond. The larger cavities are often not entirely filled but minerals project in crystals from the walls. During the process of crystallization there is a contraction of volume in cooling magmas forming minute interspaces or pores between the grains, and sometimes distinct cavities are produced, the walls of which become lined with large, well-formed crystals of the minerals composing the rocks. These are known as *miarolitic cavities* from the Italian name for a granite in which they occur (miarolo). The cooling and concentration of a

body of magma also manifests itself in the rocks in the form of *joints* which run in various directions dividing igneous rocks into variously shaped blocks and permitting the entrance of air and water to act as agents in weathering and decay. *Columnar structure* is a type of jointing best exemplified in basalts, though it is found in all kinds of igneous rocks and in both extrusive and intrusive occurrences. The whole rock mass is made up of columns fitted together in a regular manner. Such columns vary from a few inches to several feet in diameter and from a foot to one or two hundred feet in length. In a lava flow or intruded sheet, such as forms the Palisades of the Hudson, the columns are vertical; in a dike, more or less horizontal.

Relative age of igneous rocks. This is determined by their relation to the country rock and to each other. An igneous rock is younger than the rock into which it is intruded. In intersecting dikes, the one that cuts across the other is the younger. A surface flow is younger than the rocks over which it flows and, when buried, older than the material deposited above. Igneous rocks also are younger than faults that displace them. The geologic age of igneous rocks can be determined only by the relation that they bear to sedimentary rocks whose age is known.

Metamorphic Rocks

Metamorphic rocks as already defined are rocks, either igneous or sedimentary, which have undergone certain alterations in mineral composition or texture or both. The chief agents of metamorphism are mechanical movements of the earth's crust and pressure, the effect of heat and the chemical action of liquids

and gases. Metamorphic rocks are most characteristic of strongly deformed areas and are also found in areas of igneous intrusion (*contact metamorphism*). The term *regional metamorphism* is used in contrast to contact metamorphism which is often quite local. *Cleavage* is developed through metamorphism by a parallel orientation or rearrangement of minerals. It is particularly well developed in the finer-grained rocks such as shales, which are converted into slates with *slaty cleavage,* as discussed under sedimentary rocks (page 56). Cleavage developed in a zone of fracture is known as *fracture cleavage.* When a rock splits easily but not as regularly as in slaty cleavage the structure is known as *schistosity* and is characteristic of schists. Sometimes, as in gneisses, *parallel linear structure* is developed by the formation of crystals with their lengths parallel to the line of least force or stress. Original structures in rocks, such as fossils, pebbles, cross-bedding, ripple marks etc., are distorted through metamorphism. Fossils may be so distorted that they are unrecognizable and may even disappear entirely.

Metamorphism of sedimentary rocks converts conglomerates into gneisses and schists; sandstones into quartzites and schists; shales into slates and schists; limestones into marbles or, if impure, into schists. Among igneous rocks, coarse-grained feldspathic rocks, such as granite, become gneisses; fine-grained feldspathic rocks, slates and schists; ferromagnesian rocks, various kinds of schists and serpentine. *Gneiss* is not only the name of a rock but also expresses texture, and when used alone means a rock composed, as granite is, of quartz, feldspar and mica with *foliated structure.* In granite-gneiss, syenite-gneiss and diorite-gneiss the first

word indicates the composition. In general a gneiss is a metamorphic rock composed of feldspar with other minerals, and having a certain texture. The color of gneisses depends upon the color of the quartz and feldspar and the relative amount of dark minerals present. They vary from almost white through light shades of red and gray into darker shades, to browns and greens and even black. *Mica-schist* is related to gneiss on the one hand and quartzite on the other. Gneiss often grades into it. Mica-schist is the most widely distributed and important of the schists. The essential minerals are quartz and mica. Different varieties of mica occur. Dark or biotite mica is common but the silvery muscovite mica is most common. The micas occur in irregular leaves with their cleavage planes in line with the cleavage or schistosity of the rock, giving the rock a very fissile character. The sheen of such schists is due to the high luster of the mica surfaces. In color they vary from very light through grays, yellows or browns, and may even become very dark if there is much dark mica present. Other schists are known as talc-schist, hornblende schist etc. *Quartzite* and *slate* have been discussed under sedimentary rocks (page 34). Quartzite is normally white or light-gray or yellowish to brown in color, but green, blue, purple, black etc. colors may be developed through included material that acts as pigment. The colors of slate are chiefly gray to dark-gray or black, depending upon the amount of carbonaceous material present. They may, however, show green colors and the presence of iron oxides gives red, purple, yellow or brown colors. The name *phyllite* ("leaf stone") has been given to a group of rocks closely connected with slates. These rocks split into exceedingly thin sheets and differ from ordinary slates in containing

a large amount of mica, a fine, scaly, silky variety of muscovite known as *sericite.* Due to crustal movements the surface is flat or sometimes curved, folded or crumpled. Phyllites may have been originally sedimentary rocks or igneous rocks which have in the process of metamorphism been subjected to pressure and great shearing. *Marble* is a metamorphic product of sedimentary rocks composed of carbonate of lime, such as limestone, chalk etc. When the limestones are dolomitic, *dolomite marbles* are produced; pure carbonate of lime produces *lime marbles.* Marble is a crystalline granular rock composed of grains of calcite, and unlike most metamorphic rocks is massive, showing no signs of schistose cleavage or schistosity. The normal color of marble is white but the presence of impurities produces gray, yellow, red or black colors. The great deposits of marble used for constructional purposes are the result of regional metamorphism.

* Metamorphic rocks, too, are characterized by folding and faulting. Their age is that of the rocks from which they were derived, and is sometimes difficult, almost impossible, to determine. Fossils, if still present, are a help, but more often than not they are unrecognizable or have completely vanished and age can then be determined only by correlation with rocks whose age is already known.

CONDITIONS OF LIFE IN THE SEA TODAY

Most of the formations that will be treated in this handbook are of marine origin—deposits laid down in the sea. In order to have a proper understanding of these geologic formations and the fauna they carry, it is well to know something of the conditions of life in the sea today and particularly of the animal associa-

* Something should have been said about the serpentinoid or [illegible] rocks and reference made [illegible]

tions along the shore where the struggle for existence is greatest.

Numerous studies have been made of the life of the sea independently and through numerous biological stations, such as the Danish Biological Station, the Naples Biological Station etc., abroad; and in this country such as Woods Hole, Mass.; Cold Spring Harbor, L. I.; Carnegie Institution, Tortugas, Fla.; Scripps Institution of Oceanography, University of California; Puget Sound Biological Station etc. In addition to these surveys there have been various state and government surveys, particularly under the auspices of the Bureau of Fisheries. European waters, too, are being systematically studied and particularly close surveys have been made in the waters surrounding the British Isles and in the Baltic sea and neighboring waters. The information used in this chapter has been drawn from a variety of sources, but only a few of the references that are within the scope of the reading of the amateur are given in the literature, though many other references may be found in the bibliographies of the works cited. In the following discussion more particular emphasis will be given to the animal and plant associations of the shores of the North Atlantic.

It has been estimated that three-fourths of all kinds of animals live on the land; but while less than one-fourth of the animals so far described live in the sea, they include three times as many of the major types as those inhabiting the land. The physical conditions of the different localities and situations on land are very variable. The conditions in the sea are different. There is a small temperature range; there is only a

slight variation in chemical conditions, that is, salt content of the water; and except along the shores, motion affects only the surface waters and is negligible. Animals on the land in general must seek their food. In the sea food substances float everywhere in suspension and are abundant on the bottoms. Some animals go after their food, but some just attach themselves or burrow in the various bottoms and let the sea bring them their food, and still others float surrounded by their food supply.

Bathymetric or Vertical Range

Animals and plants of the sea have a bathymetric (Greek *bathos,* depth or height; *metrein,* to measure) or vertical range and a horizontal or geographical range. The horizontal or geographical range is to a greater or less degree a matter of climate, that is, temperature. In addition, the character of the shore varies horizontally. There are rocky shores, varying according to the effects of erosion on different types of rocks, sandy shores and muddy shores, each with its characteristic life. Three primary conditions are recognized as profoundly affecting organisms and determining their bathymetric distribution: an air or water medium, presence or absence of light, presence or absence of a substratum. The first determines the method of breathing and this usually makes one situation unfit for dwellers in others; the second affects the food supply and indirectly the animal; the third determines the group to which organisms belong, for without a substratum organisms must be self-supporting, able to float or swim. The life of the sea is divided into three groups: *plankton* or floating forms (Greek, *planktos,* wandering); *nekton* or swimming forms (Greek, *nektos,*

swimming); and *benthos* or bottom dwellers (Greek *benthos,* depths of the sea), whether attached to the substratum or with powers of locomotion over it. In addition to the three primary conditions above, two other conditions affect bathymetric distribution: whether the water is salt or fresh and the increase of pressure with depth. The sea or *marine realm* (halobiotic: Greek *halos,* sea; *bios,* life) is one of three organic realms, the other two being the terrestrial (geobiotic: Greek *gea,* earth) and the fresh-water (limnobiotic: Greek *limne,* pool, marsh). The marine realm is further divided bathymetrically or vertically into three subrealms, the *littoral,* the *pelagic* and the *abyssal* (figure 12).

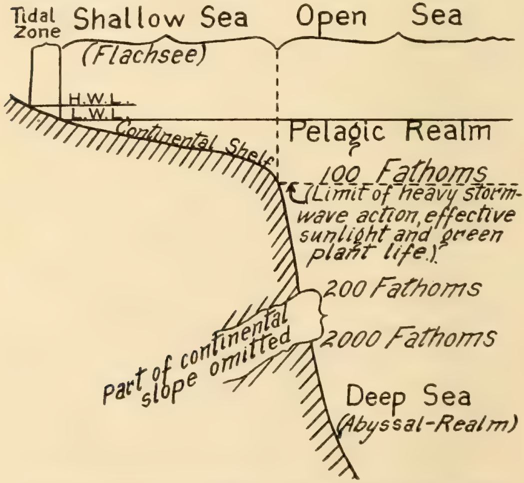


Figure 12 Diagram showing the marine realms (modified after Lull)

The *littoral* realm (Latin *litus* (litor), seashore) is composed of the *strand* and the *flachsee* or shallow sea. The *strand* is that portion of the shore included between high and low tide marks and is really a transitional area between the marine and terrestrial realms as the animals and plants dwelling there are exposed to the air twice daily by the recession of the tides. The width of this zone varies considerably, depending upon the height of the tides and the steepness of slope of the strand. It ranges from a few feet in some cases to many miles in rare cases. The *flachsee* or shallow sea comprises the waters overlying the continental shelf below low water mark and to a depth of about one hundred fathoms. The *continental shelf,* like the strand, varies in extent, growing in width at its inner and outer edges. It is formed by storm waves which cut into the shore and deposit the débris and the waste brought down from the lands over this area, particularly at its outer margin. Therefore one would expect to find it widest along old shores or where the coast is sinking, as is the case, and narrowest along new shores of continents and islands. Because there is plenty of plant food, since light penetrates all parts of this zone, and a substratum, the flachsee is important biologically. The margin of the continental shelf marks the outer limit of the action of heavy storm waves and also the outer limit of the flachsee which is about 600 feet below the surface of the sea (100-fathom line). The slope of the continental shelf up to this point is rather long and smooth, but here it descends more or less rapidly to the depths of the sea.

The *pelagic realm* (Greek *pelagos,* open sea) includes the surface waters of the open ocean down to about the

100-fathom line, the depth to which effective sunlight penetrates, which is also the limit of green plant life. This realm, besides being characterized by the presence of light, is also marked by the absence of a substratum. It has been regarded as the seaward extension of the flach-see, and is a zone of swimming and floating forms.

The *abyssal* realm (Greek *abyssos,* bottomless) includes that portion of the sea beyond the continental shelf and beneath the pelagic zone, that is, below the 100-fathom line. This realm has been divided into two zones: the zone of swimming and floating organisms where there is no substratum, the *abysso-pelagic zone;* and the zone where there is a bottom present or the *abysso-benthonic zone.* The abyssal zone is characterized by an absence of light, absence of motion, except for the extremely slow progress of sluggish ocean currents, and cold and great pressure. In the upper transitional layers of the abyssal realm there is some light but it has not the essentials necessary to the existence of plant life. The animals in this zone therefore must all be carnivorous or feed upon dead organic matter. In all the oceans below a certain depth the waters are permanently cold and have a temperature nearly at the freezing point of fresh water. Pressure in the deeps is enormous since pressure increases directly with the depth at the rate of about one ton to a square inch for every thousand fathoms of depth. All these things mean that the abyssal realm is an area of vast extent and constitutes an environment that is simple and of a comparatively uniform and changeless nature. There is corresponding response in the life of this realm.

Life in Pelagic and Abyssal Realms

The life of the pelagic and abyssal realms will be discussed first and more briefly. The plant and animal associations of the shallow waters and the strand area are of greater importance as an introduction to a survey of the geologic formations, and therefore, it is only proper to have a lengthier discussion of these life conditions and associations, which will be given later in a separate chapter. It has been pointed out that there is practically nothing in the sea which corresponds to the plant feeders of the land nor is there anything to correspond to the vegetation of the land except the seaweeds fringing the shore in the shallow waters and masses of seaweeds floating in the open ocean, such as the Sargasso Sea. There are certain small crustaceans (Copepods) which feed partially upon plants and occur in such numbers as to be comparable to a certain extent to plant feeders on land. There are also a few plant-eating mollusks, worms and echinoderms, but they do not occur in large enough numbers to be of much importance, so that the animals of the sea mainly fall into two divisions: animals living upon microscopic organisms and those preying upon one another. The shores of the sea are washed by waters bearing untold numbers of microscopic plants, small crustaceans and creatures feeding upon these. The conditions at the shore are very different from those in the open sea. Facilities for attachment are offered by rocks, stones, mud, sand, to a certain extent, and seaweeds. Plants, such as eel-grass and seaweeds provide shade and hiding places and the vegetable detritus formed where they die serves as an important part of the food of shore animals. Attached

animals are particularly characteristic of the shore. The number of kinds of animals between tides is relatively small; greater, however, nearer low tide mark. There is a marked increase in variety below low water mark. With increase in depth certain forms disappear and others take their places. Some of the shore forms disappear at about a depth of 50 feet or so. The greatest variety of animal types is found at depths of 600 to 1200 feet, on the bottom. The waters are cool and quiet, the light dim to almost absent, and the waters above and the detrital material washed from the shore furnish an abundant food supply. Animals of very large size are found in this zone including huge crabs, urchins and starfishes. Plants, that is, seaweeds, do not grow beyond depths to which sufficient light penetrates—the 100-fathom line.

The open sea is characterized by floating and swimming types. This pelagic life consists to a large extent of microscopic plants and animals, such as diatoms, foraminifera and radiolarians. The microscopic plant life is very abundant and serves as food for the microscopic animals which reproduce very prolifically and in turn serve as food for larger creatures. The micro-organisms of the surface therefore constitute the basis of all life in the sea, the fundamental food supply. The chance for diversity in the pelagic life is very small because of the simplicity of the environment. Conditions of life are very easy so there is no fierce competition, as at the shore. Far below the surface is the twilight zone where are found predaceous forms which, however, do not rise above this zone. Below this zone, again, is the region of perpetual night and cold, where the motion of the waves is never felt.

Here are new types of creatures, among them jelly-fishes, crustaceans, squids, fishes etc. of strange aspect. These animals are small or of medium size and most of them have phosphorescent lights. Animals become fewer and fewer in number with increasing depth. The greatest depth from which animals have been dredged is 3¾ miles, in the North Atlantic (a fish), and the greatest depth known in any ocean is that of 6.08 miles in a spot in the neighborhood of the Philippines. The creatures of each level in the depths feed upon the life of the level above, all therefore being supported by the creatures of the twilight zone, which in turn feed upon the plants at night. Since conditions at these levels are uniform in all oceans, the animal life is found to be practically the same everywhere and its variety lessened rapidly below the twilight zone.

The reason why marine animals are most abundant nearer land is that they are ultimately dependent upon the plant life, which in turn subsists upon the nutritive material which the rivers and streams bring down to the sea or the rains wash from the land. Thus we find that the deep waters of precipitous coasts have more deep-sea creatures than the same depths farther from the shore. It appears that the deep-sea forms are not so fundamentally different from the types of the shallower waters, but rather all seem to be migrants from shallow water habitats which have become adapted to life in the depths. There are no examples known of any new race of animals which dwells exclusively in the abyssal realm. Except for a few minor types all the groups represented in the deeps also are found in the shallow waters. The mud-eating echinoderms probably

are most generally distributed, and there is a diversity of form; crustaceans are abundant, mostly blind and spinous forms; silicious sponges are present, often very abundant, especially nearer land; all the principal groups of the mollusks are represented except pelagic forms; there are a few brachiopods; among the coelenterates a large proportion of the species is restricted to deep waters, this being the only group, however, of which this is true; almost all of the fishes are of the bony or teleostean type, the true fishes. Just as in the shallow waters, the deep-sea animals, especially echinoderms, sponges etc., have a tendency to live together in colonies with various other animals associated with them. It must be remembered, however, that life is not abundant in the great deeps. Studies of marine life have shown that the animals of the deeps are not old in a geological sense. None of the creatures of the deep-sea dates back beyond Mesozoic times, but the present shallow seas show 25–35 genera and some species that go back to the Paleozoic.

Below the deeps the sea bottom is covered with fine muds and oozes. The stillness of the water and the increasing pressure cause the deposition of the very finest muds. Beyond these muds, which are the finest materials washed out from the shores, are the various oozes composed of the shells of millions upon millions of the small creatures that die in the layers above. One of the most common oozes is the *Globigerina ooze*. This consists of the minute shells of Foraminifera, mostly species of *Globigerina*, together with some of the bottom living forms, etc. Then there are the less common *radiolarian oozes, diatom oozes* and the *pteropod oozes* composed of shells of oceanic mollusks. When one reaches the middle of the oceans the character of the bottom

changes again. The oozes give place to an excessively fine, red mud characteristic of all the abysses far from land. In this mud, as also sometimes in the oozes, have been found in scattered distribution the ear bones of whales and the teeth of sharks, some of which are of great size, several inches in length, and belong to extinct species which have been found elsewhere in the fossil state.

It is not to the abysses but to the shallower waters bordering the coast that one must go to find conditions similar to those under which most of our geologic formations were deposited, and it is in such areas that one will find life similar to that represented by the fossils in our rocks.

Geographical Range

The fact that animals have a geographical distribution has been touched upon above, and it has been shown that this factor enters little into a consideration of the deeper waters because of uniformity of conditions below a certain depth. In general, all living things in the sea have their appointed boundaries; certain types of situations always have the same groupings of animals and plants which are known as *associations*. We have animal associations, plant associations, and plant and animal associations. Each type of beach has a life peculiar to itself. The types of animals that are found on a rocky shore, stony or sandy beaches, or mud flats in one place will be found under similar physical conditions in other places. This is subject, of course, to modification by climatic conditions and over wide ranges there will be a difference in genera and species. For instance, certain sea urchins and starfishes are characteristic of the rocky shores of Maine, other forms inhabit the rocky shores of

the North Pacific coast, and yet they may be readily recognized as members of the same family. On the rocks of our northern shores Periwinkles (*Littorina*), Rock Purples, Rock Snails or Dog Whelks (*Purpura*) and Limpets (*Acmaea*) are very abundant, and near low-water mark under ledges Chitons are found; in similar places on the coast of California occur the Abalone (*Haliotis*), *Acmaea* and Chitons.

Temperature is a great factor in determining the distribution of marine life. In recognition of climatic influences upon the fauna and flora of the sea, certain geographical divisions of the coasts of North America have been recognized. On the Atlantic coast we have the *boreal fauna* from Cape Cod northward, the *American fauna* from Cape Cod to Cape Hatteras and the *West Indian fauna* from Cape Hatteras southward. The Pacific coast has similar divisions but without definite names. The geographical boundaries are not hard and fast. Some of the animals of one division pass over into the others. Many forms that normally live far out at sea drift by accident along the coast. Such are the striking Portuguese Man-of-War, the beautiful Purple Floating Snail (*Janthina fragilis*), and hosts of jellyfishes and crustaceans. The great ocean currents bring vast numbers of floating creatures from the tropics and also the arctic regions far into the temperate regions. During the winter and spring arctic animals live along our shores, while tropical and subtropical forms occur there in the summer season and early autumn. During the summer months animals whose home is normally in the West Indies or the Bahamas are carried by the southerly winds to the southern coast of Long Island; during the colder months, from November to April, under the effects

of northerly and easterly winds, hosts of creatures that make their home in the cold arctic waters appear there. Both on the eastern and western coasts of North America, in the more northern waters are species that have been distributed by way of the arctic regions and that also occur on the northern coasts of Europe. Cape Cod, in general, marks the most southern extension of the arctic fauna and the most northern extension of the southern forms. The cold Arctic Current creeps down the New England coast to Cape Cod, but south of this point, during the summer the shore is warmed by drift from the Gulf Stream. The Kuroshiwo or Japan Current of the Pacific has the same effect on the west coast as the Gulf Stream on the east. There are exceptions, of course, to this distribution of arctic and southern forms. For instance, there are a number of animals which have their true home south of Cape Cod that are found around Cape Breton and Nova Scotia where the waters at the mouth of the Gulf of St Lawrence are warmed by the last approach of the Gulf Stream to the coast at this place before it is finally deflected into the midst of the Atlantic. It is also true that animals that find their natural habitat in the cold waters of the shore farther north are likewise found in the deeper, and therefore colder waters farther south. Certain forms that are found in the shallows of the Maine coast live only in the deep, cold waters south of Maine. One should not assume, either, that animals become rare or even small in number as they reach the limit of their range. The Common Scallop (*Pecten*) is an example of a form that occurs in large numbers close to the limit of its range, for it is very abundant in Provincetown Harbor, Cape Cod, and is almost unknown north of Cape Cod.

Temperature as one of the conditions in the deep sea, as we have seen, is of practically no importance since it is about uniform everywhere and many of the deep-sea animals therefore have a range from the Arctic to the Antarctic and from the Atlantic to the Pacific. On the other hand, temperature in relation to the life of the shallower waters near the shores is so important that the creatures in the tropics of the Atlantic and Pacific, on opposite sides of the globe, are found to be quite similar, broadly speaking; yet along our Atlantic coast from north to south there are such changes in the life of the shore, more northern creatures gradually disappearing from the fauna and new forms taking their places, that along the Florida coast one finds the animals almost wholly different from those living north of Cape Cod. The fauna of arctic regions is characterized by few species with a vast number of individuals; in the tropics, on the other hand, the individuals of the species may be little or no more numerous, but the number of species is far greater.

A study of the distribution of the Algae or seaweeds of our coasts has brought about the creation of geographical divisions similar to those made for the animals. The Pacific coast, lacking the natural barriers of the Atlantic coast, fails to show distinct lines of demarcation. Upon the east coast of North America, however, four such divisions are recognized as against the three divisions in the case of the animals of those shores. The first division extends from Greenland to Cape Cod; the second, from Cape Cod to Cape Hatteras; the third, from Cape Hatteras to Cape Florida; the fourth comprises the Florida Keys and the shores of the Gulf of Mexico. There are certain algae characteristic of each of these; but, as with the animals, the boundaries are not absolute,

some species in each section extending beyond the limits of that section. In general, Cape Cod and Cape Hatteras mark the southern and northern limits, respectively, of the arctic and tropical floras. Arctic forms are not generally found south of Cape Cod, nor do many tropical forms pass north of Cape Hatteras.

Seaweeds have special habits, and certain climates and seasons are required for their growth. Sandy beaches are unfavorable to their growth, but such beaches will be found strewn with many varieties of seaweeds washed in from deeper waters, particularly by storm waves. Seaweeds love best the rocky shores and are most abundant there, particularly where the nature of the rock provides numerous crevices that give shelter from the waves. Beautiful varieties and many of the more delicate species are found in the tide pools, among them some of the red algae. Seaweeds, likewise, have a lateral or vertical zoning into three belts, the strand, the laminarian and the coralline zones. This subject will be only briefly touched upon here, but will be treated more fully later in connection with the discussion of the animal associations of the shore. The seaweeds of the *strand zone,* or area between the tide marks, are alternately exposed to the sun and air and complete submergence. Species of the very gelatinous Rockweeds (*Fucus*) are very plentiful here because nature has provided them with the means to withstand the extreme conditions they must undergo. *Fucus* and another of the brown algae, *Enteromorpha,* predominate in this zone. The *laminarian zone* comprises the area between the low-water mark and a depth of 15 fathoms. Here grow some of the beautiful red algae (Florideae) and brown algae (Laminariaceae). The *coralline zone* extends from the 15-fathom depth to a depth of about 50

fathoms. The forms here are incrusted with a deposit of lime which gives them the appearance of corals, hence the name. The Laminariaceae are brown algae and include the seaweeds that go under the names of Oarweed, Tangle, Sea Colander, Devil's Apron etc. In this group are seaweeds of enormous size, the largest known, found in southern waters and off the Pacific coast of North America. One, *Macrocystis,* has been reported with a stem one-quarter of an inch through, 700 to 1500 feet long, the leaflike part or lamina 50 feet long, and air vesicles as big as eggs. A form occurring on our northwest coast has a 300-foot stalk, a barrel-shaped air vesicle six or seven feet long bearing a tuft of fifty odd forked laminae, 30 or 40 feet long.

Struggle for Existence in Littoral Realm

The environment of the pelagic and abyssal realms is simple and uniform and life therefore is so easy that there is no fierce competition. In the littoral realm conditions are quite different. The struggle for existence is hard, and it is particularly severe, even fierce, in the strand area. The conditions with which the shore animals must contend are a sum total of those brought about by the effects of tides, currents, waves and temperature and salinity of the water. Not only are these factors to be reckoned with but there is in addition a conflict among the animals themselves and even competition within the species.

Effects of tides. The tides, with their rise and fall twice daily, force upon the life of the strand or tidal area, that is, the lower forms that are not capable of rapid displacement, the necessity of adapting themselves to

alternating marine and terrestrial conditions. In this adaptation rock pools and algae play an important part. The animals may be grouped into two divisions, nonsessile and sessile or sedentary forms. The nonsessile forms have the advantage of being able to retreat with the tide or to retire to tide pools in the case of forms inhabiting rocky shores. On sandy shores considerable moisture is held by the sand and certain forms keep in touch with moisture by burrowing in this medium. A large amount of moisture is also retained by seaweeds and under stones, and many animals take advantage of this. Crevices in rocks also afford another means of keeping in touch with moisture. The adaptation of nonsessile forms is therefore an adaptation of behavior.

The problem in relation to the tide factor is much more difficult for sedentary animals and their response is in some suitable modification in structure which aids in resistance to drying out during the hours when the tide is out. One of the best examples of this is the Acorn Barnacle (*Balanus*). These barnacles are found living on rocks so far above ordinary high water that they remain dry for days at a time, and experiments have shown that they can live for 44 days out of water. The cup in which the animal lives is covered by a valvular roof composed of four accurately fitting plates. As one walks over barnacle-covered rocks at low tide, one may hear a clicking sound due to the complete closing of these valves. At low tide the barnacle imprisons a small bubble of air between the tips of the valves and makes use of it for breathing purposes; if disturbed, the valves are completely closed and the air bubble released. Gastropods or snails use the operculum to serve the same purpose and tube-building polychaete worms have a terminal enlarge-

ment of some of the gill filaments which acts as a stopper for the mouth of the tube when the animal has withdrawn into it. The tube serves therefore to prevent dessication (drying out) as well as for protection. Burrowing is one of the commonest habits used to avoid dessication as well as to avoid enemies, and is used by many animals. The higher the position of animals along the shore the greater their capacity to resist dessication. The family to which the Periwinkles belong (Littorinidae) has been regarded as on the road to a terrestrial life. Certain of the species live above the high-water mark in shady crevices and thrive on the water from the dashing spray and moisture present because of close proximity to the sea. There are tropical species that have even less moisture. With the capacity to resist dessication in these forms goes also a capacity to endure freshening of the water. This matter will be discussed under the subject of *salinity*.

Effects of currents. Currents also play their part in the struggle for existence among shore animals. They act as an agent of dispersal for both plants and animals. Many animals that are attached in the adult stage are free-swimming or floating in the early growth stages and are therefore for a time part of the plankton of the sea, and subject to the action of currents. Many of these forms, when it comes time to settle, return to some place near the point of origin, but others have been carried by the currents to far distant places whence there is no return and to which they must adapt themselves. The region may be more or less favorable. If too unfavorable, they succumb and die; if the conditions are favorable enough to secure a foothold, they still are forced into competition with the local species which may be more

suited to their environment. Sometimes a new form is better fitted for the struggle than some local species; it thrives and continues to multiply at the expense of other species until checked by limiting factors. Currents, then, play their part in bringing new forms to other coasts and in spreading those forms introduced along such coasts so far as environmental conditions will permit. A case has been noted of a new species of seaweed which suddenly appeared along the coasts of Cornwall and Brittany, but within a few years had become completely naturalized. An example of such a complete establishment of a new species is seen along our own North Atlantic shores in the common and very abundant Periwinkle (*Littorina*). Records show that this snail was carried in ballast to the Canadian coast at Bathhurst, N. B., in 1855 and from there it has spread down the coast as far as New Haven. Its advance south of this point has been checked by the warmer temperature of the waters which has a fatal effect upon the floating egg masses. The Acorn Barnacle establishes itself very readily wherever it is carried and even colonizes on the most wave-swept rocks and boulders, being most abundant on the rocks between three-quarters and full tide. It is therefore one of the first forms to appear on a rocky shore severely battered by the waves, and the last to disappear when conditions are severe, even surviving the Rockweed. Studies along various sections of coast have brought out the fact that certain forms seem to be more or less constant and characteristic of those areas; but there are other forms that vary quite considerably both in distribution and in frequency. Certain tropic forms of seaweeds have been found to have a periodic coloniza-

tion in more northern areas through the action of currents or floods from the tropics.

Effects of waves. The waves just about share honors with the tides in making life difficult for shore forms. The influence of wave-shock upon the shore animals is very profound, and the suggestion has been made that it is not too far-fetched to regard the sedentary habit as a result essentially of this factor in the environment. Indeed it is particularly as regards habit and form of shore animals that the influence of waves has been most profound. The exact effect of waves upon organisms depends upon whether they live on a firm or on an unstable foundation. Animals living on rocks and boulders may have the protection of seaweeds such as our Rockweeds (*Fucus*) and other brown algae, such as *Ascophyllum*. The seaweeds form a natural cover and are effective in absorbing the shock of the waves, particularly the long-stranded *Ascophyllum*. Aside from this the animals living on rock or other firm foundation meet the condition to which they are exposed by seeking some sheltered position, by special powers of adhesion, and by a body form which is adapted to lessening friction. Rocks, particularly stratified rocks, offer nooks and crevices suitable for hiding and the shore animals also hide under stones as well as the seaweeds. If the rocks are stratified, the amount and direction of the dip of the beds are important. Rocks with a high dip either toward the sea or land, under the effects of erosion, afford many places for shelter and the chances of being dislodged are greatly reduced. When such rocks dip seaward the fauna is on the more sheltered, landward side and is a good fauna. Such sheltered places are often sought for spawning. On

the contrary, rocks with a low angle of dip permit the waves to sweep the whole surface and rocks barren of life are the result. Igneous rocks under the erosive action of the sea often present a smooth, rounded surface which does not give a good foothold. Some species of animals are protected by the burrows which they make for themselves, and among these are bivalves of the genera *Saxicava, Pholas, Petricola* and *Teredo*. *Saxicava rugosa* burrows in rocks and these burrows in limestone rocks are often occupied by one of the polychaete worms (*Eulalia viridis*). *Pholas* gouges holes in both rock and wood and sometimes, like *Petricola,* in hard clay. *Teredo navalis,* the "Ship Worm," burrows in submerged timbers and has done great damage to ships, piles of wharves, buoys etc. There are many forms of these boring mollusks in southern waters. There is another very interesting type of shelter. Elaborate grottos are formed by the tubes of one of the tube-building worms (*Sabellaria alveolata*) and these offer shelter and protection to whole associations of shore animals.

Many of the shore forms are attached. Some of them are permanently fixed, as sponges, hydroids, bryozoans, corals, tunicates etc. and these die if they become detached; others, like the sea anemones, are normally fixed but are capable of changing their foothold; then there are groups such as the gastropods and chitons, which are attached to rocks or seaweeds by a broad foot. The area of attachment of sedentary animals is in general well supplied with mucous glands through which attachment is effected. This is true of most of the gastropods, though the Limpets probably adhere in the same way as the anemones by a very close apposition of the pedal disc. The Acorn Barnacle has definite cement glands. The

tunicates are fastened by a fusion of the area of attachment with the surface to which they are attached by some chemical reaction. Shore turbellarians, (Planarian or Flat Worms) have adhesive papillae at the pointed hind end or sometimes all over the body and the shape of the body also is designed to withstand the shock of waves. Nudibranchs, or naked mollusks, have mucus chiefly on the foot, especially at the posterior end, but they also have a string of mucus attached to the end of the tail by which they are anchored.

The above are some of the special powers of adhesion adopted by shore animals to withstand the impact of the waves. In addition, certain shore animals have a form of body adapted to minimizing friction. The turbellarians cited above, some of which are leaflike, are one example and the flattened nudibranchs another. Some species are incrusting forms and solve the problem in this way. There are incrusting plants, such as the incrusting, stony *Lithothamnion* and incrusting sponges, hydroids, bryozoans, compound tunicates etc. Shore crustaceans show some influence in a flattening of the body. The amphipods, exemplified by the common *Gammarus* or Scud, show a lateral flattening, and the little isopods show a dorso-ventral flattening. Dorso-ventral flattening is especially characteristic of the shore crabs. The limpet form is the common shape along the shore, and is a direct result of the environment. There are numerous gastropods which are squat forms. The shells have a low spire or are devoid of a spire and there is little or no ornamentation. Studies of shells of certain species have brought out the fact that the character of shells varies with the type of situation; there is a direct relation between the form of the shell and the degree of exposure.

It has been observed that Limpets that live on exposed flat surfaces have a shell that is typically low and broad; but the same species on more sheltered surfaces develop shells which are typically high and narrow. The common Dog Whelk or Rock Snail (*Purpura lapillus*) has also been studied along these lines. In very exposed places the individuals have stunted shells, with a short spire, and they have developed a large mouth to increase their power of adhesion. In sheltered places, such as estuaries and narrow straits, the individuals grow to a comparatively large size; the spire is always well developed, sometimes even produced; and the mouth is small in proportion to the size of the shell.

Animals living on sand or other unstable deposit have an even more difficult problem to meet than those living on rock or other firm foundation. With such an unstable habitat no powers of attachment are of any service and the safety of the animals therefore depends mostly upon speed or ability to burrow. Starfishes, such as the common *Asterias,* lie rigid on the bottom with their arms extended, which minimizes friction, and they also have the power of sinking vertically into the sand. Swimming crabs escape beneath the surface by very rapid shovelling with the swimming feet. The Sand-eels that live along sandy shores between high and low tide marks also burrow rapidly beneath the surface to escape the action of the waves. There are a number of snails, such as the Moon Shells (*Natica*), Whelks (*Buccinum*), *Nassas,* Bubble Shells (*Bulla*) etc. living on the sea floor which have no special defenses against the action of the waves, but they all burrow. Indeed on sandy and muddy bottoms burrowing is the outstanding method of gaining protection, and mollusks of the sand are mostly burrowers. Some

of the bivalve mollusks are particularly adapted by their compressed and hatchet-shaped forms for burrowing. The Razor Shells (*Solen*) and Sword Razors (*Ensen*) have elongate valves which are oval in cross-section, and these bivalves and similar forms burrow rapidly and deeply. The common Soft-Shell Clam or Gaper (*Mya arenaria*) is also a deep burrower. Such deep burrowers as these have a lengthened siphon and hence a prolongation of the posterior part of the shell. The valves of the shell are not closed and serve only as fenders against the lateral pressure of the surrounding material, sand or silt. Animals that seek shelter from the strain in quieter waters or deep burrows, develop less heavy and solid shells. Mollusks of the sand, however, that are not deep burrowers are subject to considerable pressure from the shifting of the surrounding loose material and they have in many cases developed heavy, more or less globular shells, as seen in the Cockles (*Cardium, Isocardia*), the Little Necks or Hard-Shell Clams (*Venus mercenaria*) etc. Globular forms that are shallow burrowers often have ridges on the shell or other outgrowths that firmly anchor the animal. The Spiny Cockle, which is also known as Red Nose because of its bright red foot, has spines recurved in the direction of its tube which moor it securely. All of the cockles are more or less ribbed and a number also have spines to a certain degree. *Venus verrucosa* has habits similar to those of the Spiny Cockle and its ridges serve the same purpose as the spines of the latter. The Pelican's Foot (*Aporrhais pes-pelicani*) of European waters, and its western relative (*A. occidentalis*) are gastropods with heavy shell, living on the surface of the bottom. The shell has a winglike extension which seems to serve as a sort of counterpoise that enables a

slight current to return the animal to its normal position when overturned. The Scorpion Shell (*Pterocera*) of tropical seas has a similar winglike extension. This form does not inhabit American waters but is allied to our Wing Conchs (*Strombus*).

Effects of varying temperature. Temperature and salinity vary little even at a comparatively small depth in the sea, but along the shore both these factors are important. In shallow waters, particularly between tide marks, the influence of sun, air and fresh water are felt and there are wide changes both in temperature and salinity of the waters. Temperature in relation to the climatic divisions has been touched upon to a certain extent above. In considering temperature as a factor one must take into consideration both daily and seasonal changes. Animals of the temperate and arctic regions are less affected by wide changes of temperature than animals of the tropical seas, because the variations at the surface in the tropics are slight even between the summer and winter season, so that they are more affected by greater variations when they occur. Temperate and arctic animals can endure excessive cold better than tropical forms can undergo excessive heat. An example has been noted of an occasion at Tortugas, Florida, when there were several hot, calm days and the temperature of the shallow water over the Bird Key Reef rose to 92°F–100°F, resulting in the death of many animals such as the octopus, small fish and a number of mollusks over extensive areas. Even the corals were injured. To live through the year in shallow waters, tropical animals apparently must be able to survive a temperature of about 85°F(29°C). Experiments suggest that where high temperatures bring about

death it is by causing asphyxiation. It has been found that corals that can endure a high temperature of the water can endure being buried in mud for a long time without being smothered, while corals that succumb in lower temperatures are smothered during a short burial in mud. Some forms in tropical waters pass through a quiescent phase during the greatest heat of the day and when it is cooler later on become more active. Tropical animals live within about 20°–30°F of their upper death limit and within about 10°F of their temperature of maximum activity. Temperature in general is a very effective barrier to extensive geographical range, but some animals do adapt themselves outside their own range and, exceptionally, even have a wide temperature range. The Horse-shoe Crab (*Limulus polyphemus*) is a tropical form which has a range from Maine to Yucatan. At its northern limit it survives being frozen in ice and in its southern range, it can endure temperatures up to 112°F. There are certain forms, however, that are confined to the tropics because when they are exposed to temperatures of 50°–54°F they lose the power of movement.

Of course the effect of varying temperatures is seen in its acutest form in the shallow waters of the tidal zone, and that is why the animals of the tidal area seek shelter under seaweed or boulders or in tide pools, or otherwise protect themselves. The higher portions of the tidal area are most affected. Not only is there exposure to the air and the drying effects of winds, but there is exposure to the sun. The seaweeds of this zone are protected by their gelatinous composition. The type of substratum is very important in considering temperature effect. When the tide is out rock surfaces become greatly heated unless they are covered with a heavy growth

of seaweed. Rock pools even are affected unless they are deep and shaded. Daily variations in temperature are more noticeable in more northern waters than in the tropics, but the seasonal variations are most important, particularly along coasts where the climate is so cold that the water freezes and the life of the tidal area is exposed to prolonged frosts during the many hours each day that it is uncovered. We have here not only the injurious results of the frosts, but the even more destructive effects resulting from movements of ice due to tides and tidal currents or storm waves. Rocks, large stones and boulders get quite thoroughly scraped. At Wood's Hole, Mass., where parts of the coast are at times almost entirely frozen over, the rocks have been found to be scraped almost entirely bare of algae by the time the ice disappears in the spring. As we should expect, therefore, Arctic and Antarctic shores have no invertebrate animals. Great damage is often done to mussel beds through intense frosts, especially high up where they are exposed by the retreating tides. Such an occurrence is recorded from the Lancashire coast, England, where, during a spell of cold one winter, the whole coast was covered with ice-floes for a long time and the cockles were killed in large numbers. The first storm following the frost washed up dead cockles by the hundreds of tons. Certain animals avoid the severe effects of seasonal changes of temperature through seasonal migrations. Crustaceans, such as the lobsters and crabs, migrate to the deeper waters in the cold season. The decomposing beds of seaweeds along the shore that serve as a refuge to creatures needing moisture in the summer, serve also as a warm shelter during periods

of frost and cold. Sand Hoppers along the beach have been found burrowing for several inches into these masses of seaweed which in the process of decomposition produce great heat.

Effects of variability in salinity. Variation in salinity of the sea water, especially if it is abrupt, has a disastrous effect. The normal salt composition of sea water permits the development of a fauna rich in species and genera. If there is a reduction in the salt content of the water the result is an impoverished fauna, that is, a fauna poor in species, poor in lime and dwarfed in size, though often rich in individuals. Marine animals have been divided into three groups according to their ability to live in water of various degrees of salinity: (1) types (*stenohaline*) that can not live in water with less than 30 or 35 parts per thousand of salt (normal open sea); (2) types (*euryhaline*) that can endure without injury a considerable freshening of the water—they need the salt but not a definite percentage, and will live as long as any salt remains; (3) types (*brackish-water*) that are adapted to a small amount of salt and an increase of the salt is just as harmful as a reduction. The brackish state of water has not been exactly defined but the upper limit is two or three parts per thousand of salt. The types of the first division outnumber those of the other two in all groups of animals. Fresh water is poisonous to the majority of marine animals. The whole question is one of the degree to which the living tissues of the animals can be permeated by solutions of varying composition and density. It has been found that the salt content of the blood of the Shore Crab (*Carcinus moenas*) varies

with the degree of salinity of the water in which it is living.

Experiments have been made with marine animals to determine whether they can be induced to live in gradually freshened water. It was found that almost all species of marine mollusks die if they are brought suddenly into fresh water but that many species can endure the gradual addition of fresh to salt water until eventually the water has become quite fresh. Nearly related species behave very differently in this respect. The experiments have also shown that the powers of adjustment of shore animals to variations in salinity is relatively enormous and that animals that live near or below low-tide mark are far less able to accommodate themselves to such changes even though they may be brought about very slowly. The rock shore forms, such as the Acorn Barnacles (*Balanus*), Limpets (*Patella*) and the Purples or Rock Snails (*Purpura*) and estuarine forms such as the Oysters (*Ostraea*), Cockles, (*Cardium*) and Common Mussels (*Mytilus edulis*) are able even to endure water that is completely fresh; but forms such as the Scallop (*Pecten*), Abalone (*Haliotis*), Waved or English Whelks (*Buccinum undatum*), Tellens or Tellinas (*Tellina*) etc. die before the completion of the experiments. A bryozoan (*Membranipora*) has been found living in brackish water that had one-tenth of the normal salinity required by the species. There were minor modifications of the colony as to number and arrangement of cell spines etc. but apparently no detrimental effects. Nevertheless, even though animals may survive under these abnormal conditions, each species without doubt has its mean *optimum salinity,* that is, a salt content of the water which permits the species to reach its full development. For species

which are of economic importance, this optimum salinity has been determined.

The Baltic sea is a noted area for studying the influence of a diminished salt content upon the animal life. It shows a very striking decrease in salinity eastward and in a large way the responses of the fauna to it. The North sea has the normal marine salinity of 35 parts per thousand of salt which decreases steadily going eastward in the Baltic until at the northern end of the Gulf of Bothnia the water is practically fresh. As the salinity of the water decreases from that normal for sea water, the fauna changes from one typically marine to one in which only a few marine groups are represented and finally to a fresh-water fauna. From the Gulf of Finland is reported a *crustacean fauna* made up almost entirely of fresh-water types, one of them showing such a great abundance of individuals that it alone represented three-fourths of the mass of the animals obtained at the various stations. With these fresh-water types occurs a marine pelagic crustacean that becomes more and more abundant westward with increased salinity. A brackish-water type also occurs here and this species has so adapted itself to the extreme conditions of existence in the Baltic that it has spread out everywhere and is so abundant as to play an important part in the nourishment of certain fishes. The Gulf of Finland with its extremely low salinity may be compared to a lake broadly opened on the Baltic. Among the *Mollusca* of the Baltic a change similar to the above has been found. Brackish and fresh-water snails and even a river form are reported from the waters of low salinity, and in the Gulf of Bothnia many of the common air-breathing pond snails have accustomed themselves to the slightly saline waters of that

part of the Baltic. There is a rapid decrease eastward in the number of species comprising the whole fauna, so much so that this area has been described as being divided faunistically into two basins, a western and an eastern, the former characterized by a rich fauna, the latter by a strikingly impoverished one. About 240 species have been reported from the western basin and of these species only about one-fifth are found in the eastern basin. With decreasing salinity dwarfing appears. The animals of the eastern basin are more dwarfed than those in the western basin, and the best examples are found among the mollusks, in which group, in addition to being dwarfed, the shells become poor in lime. Two good illustrations are the Common Mussel (*Mytilus edulis*) and the little *Macoma balthica* (*groenlandica*) so characteristic of northern waters. Another noteworthy case of dwarfing is exemplified by the common European Cockle (*Cardium edule*) which has a large, rough, thick shell and thrives best under purely marine conditions. In normal conditions in the North sea this Cockle is the size of an apple; at Stockholm where the water shows only ten parts per thousand of salt, the shell is the size of a walnut; with decreasing salinity eastward in the Baltic, the shell at Königsberg reaches the size of a hazelnut, and at Reval only the size of a pea. A very important fact brought out in the studies of the Baltic sea is that however dwarfed or otherwise modified the species may be the marine forms of the Baltic are not different specifically from those living in water of normal marine salinity, nor do the fresh-water forms differ specifically from those found in the rivers emptying into the Baltic or those in near-by fresh-water bodies.

Examples of dwarfing due to freshening of sea water have been noted elsewhere than in the Baltic. The European Cockle is very common along the British coast, but it is found in a dwarfed condition in the brackish waters of the estuaries. The shell is also thin and with less strongly marked surface characters. The cockle of the Greenland estuaries has a shell that likewise is thin, smooth and almost without teeth. Both the Caspian and Black seas have fresher water than the Atlantic, and they, too, show dwarfing of the cockles. Among other species that are dwarfed by brackish waters, are the Long or Soft Shell Clam (*Mya arenaria*) and the Periwinkle (*Littorina littorea*). Even higher forms are affected. Dwarfed fishes have been found in the Baltic and the Black seas and the modifying effect of brackish water on the fishes has been noted elsewhere.

A recent study by the writer of the Pleistocene fauna of the St Lawrence-Champlain area brought out the fact that the Champlain fauna is a dwarf fauna, due in large part at least, to decreasing salinity southward in the waters of that time. The conditions were similar to those in the Baltic today. The dwarfed character is particularly well-shown by five species: *Macoma balthica (groenlandica)*, *Saxicava rugosa, Yoldia arctica*, the Common Mussel (*Mytilus edulis*) and the Long Clam (*Mya arenaria*). Just as is found in the Baltic, so here, along with the dwarfing of species goes a decreasing thickness of shell and there is some variability of form.

Bearing in mind all these facts, we can understand better the effects of changes in salinity of the water at the shore. Rivers and streams are constantly bringing fresh water from the adjacent land to the sea and it is the littoral waters that are affected. The effect of these fresh

waters is most marked in the neighborhood of small bays or estuaries and there are certain seasons when the influence is greater. The invariable presence of the green seaweed, *Enteromorpha,* along shores is a witness to the fact that there is hardly a patch of the rocky foreshore which does not receive its share of fresh water, for otherwise it would not thrive. Even the life of the shore pools does not escape. Conditions of life here are affected by the same phenomena that cause variability in the temperature and salinity of the coastal waters. Heavy rains freshen the waters of the pools, and under the influence of a strong sun evaporation increases their salinity. The salinity of rock pools has been found to vary anywhere from a little above two or three grams of dissolved salt to about a quart of water to over 300 grams of salt per quart. Such pools are inhabited by protozoans and small crustaceans in large numbers. Studies of certain of the flagellate protozoans of shore pools show that under the most favorable conditions they may be present in such numbers as to color the surface of the pool green. If the water evaporates until it is strongly saline these small organisms come to rest, showing no signs of life. This is known as a period of latent life and they remain in this state until the condition of the water again becomes suitable, which may be even for two or three weeks. The little crustaceans (*Copepods*) may also have to contend with severe conditions, since in wet weather the pools may be flooded and in a dry summer may be even completely dried up. The green seaweed which covers pools above high-water mark is a shelter and refuge for enormous quantities of these small forms. They thrive best in the pools when the water in the pools is fresher and experiments with some of them have shown that both

they and the green seaweeds thrived in practically fresh water, the copepods increasing greatly in numbers and being very active. Under conditions of evaporation the copepods live until the water is almost entirely gone, seeking refuge within the green seaweed after evaporation has been going on for some time. Salt marshes show even more variability in salinity of water than the rock pools and require similar powers of resistance for the life inhabiting them. One of the most extreme adaptations to strong saline conditions is illustrated by the Brine-shrimp (*Artemia salina*), which lives in brine pools. This is a small, shrimplike form that inhabits European salt marshes (Lorraine; Cagliari, Sardinia), resisting densities as great as one to 16 or one to 23. In the country around Cagliari there is a gray salt used, in which are found the eggs of this crustacean. These eggs will develop normally when in water of suitable salinity.

Conflict between animals themselves. Not only is there the struggle of the shore animals to adapt themselves to the physical conditions of their environment, but there is also a sharp conflict between the animals themselves which has led to methods and weapons of attack and defense. Some form of protective armor is of frequent occurrence along the shore, such as the shells of mollusks, the spines of sea-urchins, the tubes of worms, the tests or shells of crustaceans etc. Crustaceans, such as lobsters and crabs, have chelae or pincers as weapons of defense; hydroids, jelly fishes and sea anemones have stinging capsules or nematocysts for paralyzing their prey; mollusks, otherwise defenseless, have the strong adductor muscles that close the shell. There are boring gastropods that prey

upon other mollusks, as the *Urosalpinx* or Oyster Drill that is so destructive to oyster beds; there are also boring sponges. Starfishes prey upon bivalves and are very detrimental to mussel beds. In no other area are the weapons of offense and defense and the tactics of warfare so varied as they are at the shore. Apart from the distinct organs of offense and defense, there are distinct habits or tactics which are the outcome of the shore struggle. Among the tactics to escape pursuers are hiding, masking, protective coloration or resemblance, warning coloration, mimicry, death-feigning, rapid flight etc. Sometimes these tactics are aggressive in character, helping an animal stalk its prey. Hiding is one of the commonest means of escaping pursuers. The animals using this method hide under stones or seaweed, burrow, or, as the Hermit Crab, take refuge in empty gastropod shells. Crabs (*Carcinus, Cancer*) and other crustaceans make use of death-feigning or hypnosis. There is a sudden cessation of activity and the animals give the appearance of death. In protective resemblance there is a close resemblance to the surroundings. Crabs are found resembling pebbles, branches of coral, mollusk shells, muddy surface of limestone etc.; nudibranchs are found on green or red seaweeds according to their color; the polychaete worm, *Eulalia viridis,* is found on green seaweed, *Ulva,* which blends with its own green color. Many examples of this kind might be given. In contrast to this, some coloration is very conspicuous and is associated with unpalatability or qualities which make the animal dangerous to eat. It therefore acts as warning coloration. There have been recorded only a few cases of mimicry at the shore, that is, resemblance of some harmless form to one that

has means of protection. Masking, on the other hand, may serve for the purpose both of defense and offense. The long-legged Spider Crabs plant on their carapaces seaweeds, sponges and hydroids which make them almost invisible when they are in their natural environment. Some sea anemones (*Tealia*) cover their bodies with bits of shell and gravel to conceal themselves from their prey. Certain crabs (*Melia*) carry sea anemones (*Sagartia, Bunodeopsis*) around in their claws. The crabs carry sometimes one species of anemone, sometimes another, and will throw aside a small one of one species to take up a larger one of another. The crab uses the anemone for two purposes. If the crab is irritated it thrusts its claws toward the direction of trouble placing the anemone with its stinging nettles in the most favorable attitude of defense or offense. In addition, the crab profits by the food secured by the anemone.

Certain animals have the power of autotomy (self-amputation) and regeneration, that is, they can regrow parts of the body which they have lost through accident or attacks of other animals, which is a form of protection or defense. Among the crustaceans, such forms as the prawns, lobsters and true crabs have the power of throwing off the legs, which they do when the limb is roughly held or crushed. These animals may therefore be found with unequal claws or walking legs, while the process of regeneration is going on. In starfishes and brittle stars there is self-amputation of the arms. Starfishes can not only regenerate an arm, but a single arm with a portion of the disc attached can generate a whole starfish. That is why starfishes are found with such unequal rays or arms. Brittle stars may shed the arm in one piece, or the

arms may be broken off piece by piece until only the disc remains. In sea cucumbers autotomy involves the internal organs and is a process of self-evisceration. This happens when the animal is strongly irritated and may involve part or the whole of the viscera, regeneration taking place in a fairly short time. There are other miscellaneous cases of regeneration but these are among the most striking.

Through the crowded conditions along the shore another type of struggle is brought about. There is a tendency for many organisms to live on the bodies of others. Small seaweeds grow upon the shells of slow-moving gastropods such as Limpets and Periwinkles. Various seaweeds are also found attached to the species of the Shore Urchin (*Echinus*); and one of the green seaweeds (*Enteromorpha*) often marks with its tufts the position of Cockles in the sand. The broad fronds of seaweeds are of advantage to incrusting animals. The empty air vesicles of the brown seaweed *Ascophyllum* house the larvae of the Common Mussel (*Mytilus edulis*). Sessile forms of animals such as hydroids, bryozoans and barnacles, settle upon the bodies of other animals just as they settle upon rock. Mollusk shells, particularly the sessile bivalves such as oysters, may be heavily incrusted not only with other forms but with the young of the same species. The Slipper or Boat Shell Snail (*Crepidula*) attaches itself to other shells or to shells of the same species and five individuals have been found occurring one on top of the other. Slow moving crustaceans carry a variety of guests, among them algae and hydroids which may be of advantage in that they serve to conceal the host. The higher crustaceans are liable to be incrusted with sedentary forms, especially barnacles, until the load becomes embarrassing, and molting alone frees the animal from

its burdensome collection. A single crab has been found carrying a collection of two kinds of bivalves, gastropods, barnacles, tube worms, bryozoans, various kinds of hydroids etc. The case of the Spider Crab and the sea anemone has been mentioned above. The Hermit Crab, which makes use of the empty shells of Periwinkles, Purples, Moon Shells, Welks etc. carries sea anemones on the shell which it has adopted for a home. One species of anemone (*Adamsia palliata*), a European form, is always found on a bivalve shell inhabited by a Hermit Crab. Such shells have been found bearing also colonies of hydroids and species of sponges, and with bivalves, Jingle Shells (*Anomia*), inside and out. In the dirt at the bottom of the shell have been found a tube worm, a small crustacean (*amphipod*) and often a small crab (*Porcellana*). A polychaete worm lived in the shell with the Hermit Crab and two parasitic crustaceans in its gill chambers. Some animals have appendages for removing foreign material, such as larvae of incrusting forms, as for example the appendages of certain bryozoan genera (the avicularia) and of sea urchins (the pedicellariae). In general the host must bear his burden, endeavoring to outgrow the guest or guests or sometimes getting rid of them through molting, as in the crustaceans. This association is to an extent harmless, but it is hard to tell at what point it ceases to be harmless, for too numerous guests impede movement and stifle growth.

In the associations mentioned above, in general the guests have used the host only as a foothold; the association may be neither beneficial nor harmful. The partnership may be of benefit to only one of the partners, such as in the protection offered to small fishes and crustaceans by the internal cavity of the gigantic sea anemones of the great Barrier-Reef and in the safe hiding

places provided by colonial forms of corals and sponges to many animals. When two forms live together with mutual benefit to both, the association is known as *commensalism.* The Hermit Crab-Sea Anemone association is an example of this. The Hermit Crab carries the anemone from place to place on its shell so that it is able to secure a more abundant and varied food supply besides getting the scraps of food the crab lets drop, and in return, the Hermit Crab can retreat into its shell and secure protection from predaceous fishes through the anemone which, because of its toughness and stinging cells, is avoided as food. It is not a long step from commensalism to true parasitism. *Parasites* are organisms that live temporarily or permanently in or upon other organisms. They feed upon them or their food and become more or less modified for this purpose. Among the shore forms the parasites occur mostly among the worms, particularly the flat-worms and the crustaceans. One crustacean (*Sacculina*) attacks the Shore Crab (*Carcinus*); a similar form (*Peltogaster*) attacks the Hermit Crab. The parasites in their adult form have degenerated and bear no resemblance to crustaceans, and in both cases have an important influence on the host. Many of the parasitic flat-worms, especially the "flukes," pass certain stages in their development in the mollusks dwelling along the shore. Pearls are formed because of the irritation set up by such parasites.

Competition within the species. Not only is there competition among the different species of animals at the shore, but there is also competition within the species itself. This is very well illustrated in the mussel beds. The young of the species settle upon the older forms and grow there. This may be continued

to such an extent that the mussels often are so numerous as to occur growing upon one another to the depth of several layers. The older forms gradually become smothered beneath the ever-growing mass of younger forms, and the mussels also actually poison one another.

Factors dangerous to eggs and larvae. To a certain extent the eggs and larvae of shore animals have to contend with the same factors that make the struggle so fearful for the adults of the species. Since the larvae, often the eggs too, are part of the pelagic life of the ocean they for a time escape some of it. For both eggs and larvae there is danger of being stranded on the shore or swept out to sea; danger from variation in the environment due to tides, temperature changes etc.; danger from predaceous animals. For the eggs there is the risk of dessication when the tide is out; for the larvae, the risk of failure to obtain a foothold. To offset these dangers the spawn of shore forms is often attached and is given the additional protection of some form of horny or gelatinous covering. There is also a tendency to modify the chapters in the normal life history according to need. Under certain conditions the larval period may be prolonged; under others it may be condensed, as in forms living at high-tide mark (for example, Periwinkles). The period of reproduction is often adapted to the seasons or coincides with some particular phase of the moon which gives the larvae the best chance of survival. It is obvious, therefore, when eggs are liberated at random without parental care, that they must be produced in large numbers. In contrast to this, some of the shore fish produce a small number of eggs because they have acquired the habit of parental care.

PLANT AND ANIMAL ASSOCIATIONS ALONG THE SHORE

As has been mentioned in the previous section, shores may be a succession of rocky, sandy or muddy beaches, cliffs, headlands, reefs, open oceans, bays, estuaries, fiords, inlets, lagoons, deltas. The rocky type of shore may have vertical cliffs with deep water; there may be slopes of varying degree, or reefs may appear. At the base of cliffs may be a mass of boulders; there may be shingle or sand, or, rarely, mud; sometimes there is a rock erosion plane. The nature of the shore line along a rocky coast depends upon the character of the rock. Igneous rocks tend to weather with a smooth surface and are not suited to attachment. Stratified rocks under weathering give a far better surface, particularly sandstone; and sandstone of finer structure bears a richer fauna than where the sandstone is coarser. Conglomerates and drifts through weathering give rise to loose detritus that forms shingle banks. Rock-boring organisms are important in the gradual disintegration of rock. Among these are sponges, echinoderms, worms and mollusks. Much depends upon the hardness of the rocks. Sand may be formed from weathering of sandstone or other rocks, comminuted shells etc. It is not always of the same texture or weight. It grades on the one side into pebbles and gravels and on the other into muds. Muds likewise show all degrees of variation in texture and composition. Sands may occupy great stretches of the open coast; muds are deposited under more sheltered conditions, as in estuaries, bays, other inlets, mouths of rivers and creeks etc. or farther out in the

quieter waters over the continental shelf. Especially in estuaries plants are an important factor in building up mud flats until they become firm ground above the influence of the sea. There is a tendency toward the formation of tide channels in weak spots, and mussels line the muddy banks of such channels to such an extent that erosion is almost stopped.

The nature of the shore at a certain spot plus the other physical conditions with which organisms must contend determines the character of the plant and animal associations. If there is a uniformity of physical conditions over considerable areas and distances there will be a most pronounced and well-marked fauna, but also a more limited one than where there is a diversity of conditions. If the substratum in two places is the same, then any difference in the flora and fauna is due to difference in exposure. Some forms can not stand much exposure, others require a certain amount of exposure. If a sandy beach succeeds rocks along the shore there is a change in the type of life, but when the same type of shore appears again, the same plant and animal associations reappear. There is also this to be remembered, whether along the Atlantic, Pacific or other coast, whether in tropical, temperate or arctic regions, the same type of shore under the same physical conditions (exposure to winds, tides etc.) will show the same character in the plant and animal associations. The species, even the genera may be different, but the types are the same. In an association a normal relation between the various members has come to exist. There are a certain number of genera, species and individuals which may be looked for in an association. Where there are several

species of a type present one is apt to be the most abundant and may be the dominant species. In one species the individuals may be small but very numerous, while larger, more conspicuous forms are present in relatively small numbers. There is a pronounced variation in the extent to which the different phyla are represented in the associations. The mollusks are found on rocks and in tide pools as well as on sand. In the former situations one finds the mollusks fewer and of the creeping type, and therefore the gastropods predominate; in sand, however, mollusks are numerous, mostly of the burrowing type, and here the lamellibranchs or bivalves predominate. In the rocky pools the coelenterates, such as the hydroids and sea anemones are well represented. In all the associations, it has been noted that a balance is maintained between vegetable species, predatory species and parasites. Otherwise, changes in the association would result.

The three main types of shore recognized are (1) rock, (2) sand, (3) mud. There are a number of subtypes within each type and between the different types. Some in studying beaches recognize a submerged zone, the lower beach and the upper beach; others have divided both the sandy and muddy beaches into a number of zones. Rocky shores are likewise so treated. The area between high and low tides can usually be split up into a number of life zones which are characterized by certain assemblages of forms. These forms may be confined to that one zone or if present in other zones may in the former be predominant in numbers or have some well-marked character which gives a distinctive, readily recognized, appearance or *"facies"* to that particular horizon. Associations of the

various types of shore also differ somewhat on the open coast from those in bays and estuaries, although the general character of the assemblages is the same. Besides the above, there are other types of associations to be considered, such as the life of the brackish waters in estuaries, harbors and marshes; the life of wharves, piles etc.; the life of reefs, the life of shelly bottoms etc. It would be out of the question and also not fitting to take up in this chapter a detailed and complete discussion of all the types of plant and animal associations. It is proposed to give here mainly a picture of the assemblages of life characteristic of each of the three main types of shore, rocky, sandy and muddy, so that the beginner in studying our geologic formations with their fossil content may have some idea of the conditions under which the life of those ancient times existed. Also, emphasis will be placed upon the life of our Atlantic coast, particularly the northern shore, noting, however, where there is a particularly long range.

Rocky Shores

The vegetation of the sea is definitely limited to the surface (plankton) and the shallow waters and is quite conspicuous at the strand, between tides. *Seaweeds* find places of attachment along rocky shores and they, as well as the crevices of the rock, afford shelter to many animals that could not live in more open and exposed places. The Rockweeds (*Fucus nodosus, F. vesiculosus*) occur from near low-water mark of ordinary tides to nearly half tide, and they form large beds of vegetation very conspicuous on our rocky shores when the tide is out. Above the *Fucus* zone another brown seaweed (*Asco-*

Figure 13 Exposed rocks at East Point, Nahant, Mass. The left side is toward the open ocean. The seaweeds *Ascophyllum* (*a*) and *Fucus* (*f*) pinch out and are replaced by the barnacle *Balanus* (*b*). (Courtesy Wisconsin Nat. Hist. Soc.)

Figure 14 An abundance of the periwinkle *Littorina littorea* and the barnacle *Balanus* on a rock when boulders are present, Nahant, Mass. (Courtesy Wisconsin Nat. Hist. Soc.)

phyllum) grows in abundance, also giving shelter and breaking the force of the waves with its mat of long strands. *Fucus* and *Ascophyllum* often become so dry between tides, that they crackle and break when touched, but they are apparently uninjured and soon become pliable when wet by the incoming tide. The Irish Moss or Chagreen (*Chondrus crispus*) may be found along the New England coast forming a thick carpet on rocks from a little above low-tide mark to a considerable depth. Below the *Fucus* zone and only exposed during spring tide are the Sea Lettuce (*Ulva latissima*) and many other more delicate green and red seaweeds. Rock pools often contain beautiful varieties of the more delicate species. Red seaweeds are sometimes found on the shady side of these pools, and in the larger pools also are found a rich growth of a red coralline alga (*Corallina officinalis*) and specimens of Laminaria (brown alga), some of quite large size. The brown seaweed known as the Sea Colander also occurs in such pools, and red algae are sometimes so plentiful as to redden the rocks. The green seaweed *Enteromorpha* with its ribbon or threadlike strands is also found in pools. This form is widely distributed and very abundant. Some of the red and brown seaweeds form feathery plumes often a yard long in deep tide pools, and numerous tufts of the red algae and others are found growing on the Rockweeds.

On seaweeds, particularly the larger ones, lives a varied fauna. Certain species of sponges are found on seaweeds. Many of the branched hydroid colonies are littoral and among other places live on the hanging *Fucus.* The sertularian hydroids are found everywhere along the coast and are among the most common objects cast up on the beach. They resemble delicate, plumelike sea-

weeds and are often pressed for them. One species (*Sertularia pumila*) is the most abundant of all the hydroids upon the New England coast and is found in profusion in sheltered situations on *Fucus* and other seaweeds, as well as on rocks. Another species (*S. argentea*) is common from New York northward. Another hydroid, the Sea Plume (*Obelia commissuralis*) also is found attached to seaweed. It, too, is plumelike in appearance and has main stems six inches in length. A small iridescent jellyfish (*Lucernaria auricula*), about one and a half inches in diameter, may also be found attached to *Fucus*. It is also found attached to eel-grass, though sometimes free. On seaweeds below half-tide mark are found worms leaf-like in form (polyclads). There are several bryozoans or Moss Animals found on seaweeds. A calcareous form (*Crisia*) forms bushy tufts one-half inch to one inch high on seaweeds in tide pools, especially red seaweeds. This is a very common form from Long Island Sound northward and also occurs on the Pacific coast. There are other white, calcareous colonies found on seaweeds and also on eel-grass. Still another species forms white, creeping, calcareous stems on seaweed fronds. The Lace Coralline (*Membranipora pilosa*) is an incrusting variety that sometimes completely covers the fronds of seaweeds and is especially common on Kelp. It is abundant on shores from Long Island to the Arctic and is also found on the northern coasts of Europe. Another species occurs from New Jersey northward. Certain tiny creatures known as Sea Spiders (*Pycnogonida*), because of their resemblance to the spiders, may be found crawling over hydroids and seaweeds. They are purple, gray or brown in color. Another curious little animal, a crustacean (*Caprella geometrica*), is also found in abundance

clinging to hydroids and delicate algae, resembling in color and often in form the objects on which it lives. It holds on by the posterior feet and sways back and forth like the hydroid or seaweed on which it lives, and its walk is like that of our Measuring Worm. It ranges from North Carolina to Cape Cod. Some species of the genus may be found on every coast. Small jellylike masses sometimes seen at the broad divisions of the seaweed may be compound ascidians or Sea Squirts (*tunicates*). These gelatinous masses are globular or domelike, tough and usually dull in color. Several species of mollusks, mostly gastropods, live among the seaweeds. One of the Jingle Shells (*Anomia aculeata*), a scalelike bivalve is found attached to the holdfasts of *Fucus*. Several species of nudibranchs, the naked mollusks or Sea Slugs may be found. They often appear like small lumps of jellylike tissue when discovered and disturbed, but if left unmolested will unfold their beauties. One (*Eolis papillosa*) is yellowish gray to orange with purplish or olive spots. It is probably the commonest form upon the North Atlantic coast, and is found not only upon seaweeds but clinging to stones, on the piling of wharves, eel-grass etc. in shallow water. This form is also found on the shores of Europe. The Seaweed Snail (*Littorina palliata*) is common on seaweeds between tide limits from New Jersey to Nova Scotia. In color it is olive, yellow or brown, red or mottled, approaching the color of the seaweed upon which it lives, and the spire is more blunt than in the Periwinkles. The Atlantic Chink Shell (*Lacuna vincta*), closely allied to the Littorinas, occurs on marine plants in sheltered places and is found in quantity on roots of *Laminaria* washed in by storms. This snail is very abundant on the New England coast.

The *tide pools* have their characteristic life. Besides the algae already discussed, there are other forms to be noted. Incrusting red seaweed (*Hildenbrandtia*) often carpets the pools, and it is also common everywhere on stones and rocks at low water. Interspersed one often finds the deep red color of another incrusting form (*Petrocelis cruenta*) which is common north of Cape Cod. The lime-secreting red alga resembling coral (*Corallina*) has already been described. Also to be noted are the fine feathery plumes of a brown seaweed (*Desmarestia*), the fan-shaped fronds of a purplish red seaweed known as Dulse, and more delicate tufts of red and brown seaweeds. There likewise occur in these pools, typically along the New England coast, green, gelatinous, fleshy balls, looking like small green tomatoes, one and one-half to two inches in diameter. These are green algae (*Leathesia difformis*) which grow in bunches on other seaweed and on sand-covered rocks, and are found in summer on every coast. The balls are hollow and also become lobed and hollow. The vegetation of rock pools differs according to the situation within the tidal range, the geological nature of the rock, size, depth, drainage, illumination etc. In the upper pools the incrusting forms are conspicuous. Plant life becomes more abundant where there is a more gradual slope and the sides are rougher and more irregular. The higher the elevation of the pool, the fewer the species, but there may be a greater number of individuals.

Rock pools solve the problem for typically marine forms on rocky shores. Besides the algae discussed above, there are sponges, hydroids, bryozoans, nudibranchs, echinoderms, mollusks and crustaceans. Some of the more common representatives will be touched

upon. Yellow and green sponges spread over small surfaces in little cones. The Urn Sponge (*Grantia ciliata*) forms clusters of little urn-shaped bodies, one-half inch high, dull yellow, gray or drab in color. This sponge extends from Rhode Island northward to Greenland. Many of the hydroids are littoral and to be found in tide pools, among them the sertularians mentioned above, the Eel-Grass Hydroid (*Pennaria tiarella*) and the Passion Flower Hydroid (*Thamnocnidia spectabilis*). The Eel-Grass Hydroids are three to six inches high and resemble little dark-colored trees. This is a branching form found in tide pools, on Rockweed, piles etc. in spring and early summer. The Passion Flower Hydroid is found within shaded tide pools and often grows upon sunken ropes. It forms dense clusters of delicate amber-gray stems. Each stem ends in a pink-colored polyp which has two rows of tentacles surrounding the mouth. Among the bryozoans of the tide pools is to be found the Red Crust (*Escharella variabilis*) which is especially abundant in shaded tide pools from South Carolina to Massachusetts bay. It forms a dull red or purplish incrustation over rocks and dead shells, layer after layer, and bears a superficial resemblance to coral. It grows from tide level to a depth of 150 feet. The calcareous *Crisia* growing on seaweed is also present and another form (*Tubulipora*) that grows on seaweeds in corallike, fan-shaped masses sometimes one-quarter of an inch in diameter.

There are several species of sea anemones present in these pools and they may be quite abundant. The Orange-streaked Anemone (*Sargartia luciae*) is now one of the most abundant species in the rocky tide pools of Long Island sound and it extends as far north as Salem, Mass. It was not known in this section before 1892. but

was introduced from the south on oyster shells. This species is small, about a quarter of an inch wide and three-eighths high. The body is olive-green or brown in color, with longitudinal orange, or lemon-yellow, streaks; and the 48 tentacles are light brown, almost white. The Crimson or Rose Anemone (*Tealia* (*Rhodactinia*) *crassicornis*) is found in tide pools and on ledges covered with Rockweed from Cape Cod north. It is a thick-petaled form three inches in diameter and the color varies, being bluish green mottled with crimson, bright cherry-red or flesh colored. The Brown Anemone (*Metridium marginatum*) is found at low-water mark in tide pools, under large stones, in sheltered crevices of rocks, on piles and wharves. It is common from New York northward and is the most conspicuous and abundant sea anemone of the New England coast. Sometimes it measures ten inches across the disk, and there is an allied species found in Florida that measures 18 inches in diameter.

Almost all divisions of the echinoderms — sea urchins, sea cucumbers, brittle stars and starfishes — are represented in the tide pools. The Green Sea Urchin (*Strongylocentrotus dröbachiensis*) is the common species in shallow water of the northern temperate zone. These creatures are green or greenish-purple in color. In some pools they form a carpet of green spots like tufts of moss. This form occurs in the deep waters of Long Island sound; north of Cape Cod in shallow tide pools; and on the Maine coast, where it is exceedingly abundant, it literally covers the rocks. On the Atlantic coast its range is as far south as New Jersey, but in its most southern distribution it is rare and small. On the Pacific coast it extends as far south as the state of Washington. The Purple Sea Cucumber (*Thyone briareus*) is a shallow water form

ranging from Texas to Cape Cod and found in tide pools and on the rocks at low-water mark. This is a large form, four to five inches long and about an inch thick, purple in color and with the surface thickly covered with prominent papillae. Another species (*Pentacta frondosa*) is very dark purple on one side and whitish on the other, with nearly smooth surface. The body is ovate and somewhat pentagonal and when the animal is full grown measures 15 to 18 inches. This form is very plentiful on the Maine coast in tide pools and on the rocks at low-water mark. The genus has a range over the greater part of the world. The common species of serpent stars, the Brittle Star (*Ophiopholis aculeata*), is readily recognized by its mottled coloration in light gray and purplish brown. While this brittle star is abundant at depths of 100 feet, where it crawls about among the rocky crevices, it is also found, though more rarely, in shallow waters; but it is plentiful in the tide pools of the Maine coast. A similar, perhaps an identical species, occurs on the North Pacific coast. There is a tiny starfish, one-half inch to two inches in diameter and of various colors — purple, orange, red, yellow, flesh-color etc.— which is abundant in rocky tide pools from the eastern end of Long Island to the Arctic ocean. This is the Blood Starfish (*Cribella sanguinolenta*). The so-called Common Starfish (*Asterias vulgaris, A. forbesii*) also occurs in the tide pools. Both species are much larger than the Blood Starfish and are the common starfishes of the Atlantic coast. *A. vulgaris* ranges from North Carolina to Labrador, but is common only north of Cape Cod; *A. forbesii* from the Gulf of Mexico to Massachusetts bay, but is rare north of Cape Cod. These are the species particularly destructive to oyster beds. The more

southern form (*A. forbesii*) occurs from low tide level to a depth of 120 feet and may be distinguished from the more northern form by the blunt-tipped arms and the bright orange madreporic plate. *A. vulgaris* ranges from low tide to a depth of 1200 feet. In color it may be beautiful shades of pink or red, purple, yellow or brown. Both species inhabit all kinds of bottoms. Other species of this genus are common on the Pacific coast.

Mollusks have several representatives that inhabit tide pools. One of the very interesting forms found is the Chiton or Armadillo Slug, with flat oval body and back covered with eight shinglelike calcareous plates. They cling with great tenacity to the surface over which they are crawling, but roll up into a ball when torn off. The common species of our coast (*Chaetopleura* (*Trachydermon*) *apiculata*) ranges from Cape Cod to the Gulf of Mexico and is found not only in rock pools left by the receding tide but on stones and dead shells from below low tide mark. It is abundant on dead oyster shells. The color is usually dull brown or gray, but some specimens are white. There are a number of very common species along the west coast, but comparatively few along the north and along our coast they are small. In the Bahamas and West Indies there is a large Chiton about three inches long. The nudibranchs (*Eolis, Doris*) are likewise represented in the pools.

Among the gastropods are the Rock Snails or Dog Whelks (*Purpura lapillus*), the Periwinkles (*Littorina littorea* and *rudis*) and the Limpets (*Acmaea testudinalis*) found commonly along our shores. The Rock Snail occurs in myriads on the rocks and in the tide pools along the New England coast north of Cape

Cod. It is especially abundant between tides on the rocks where barnacles occur for it is a carnivorous form and feeds upon them. It is abundant on European shores as far south as Portugal and is an immigrant to American waters by way of Iceland and Greenland. On our coasts it ranges from Long Island to the Arctic ocean. The shell is never more than one and one-half inches long here, but it is larger on the northern coasts of Europe. Individuals are variable in form and color, depending to a certain extent upon the conditions under which they live. The color varies from white through yellow to chocolate. It may be banded with yellow or brown or rarely vermilion. The exterior of the shell is smooth to exceedingly rough and has numerous coarse revolving ridges. There are several species of Purpuras in the Florida waters and three species on the Californian coast. The Purpuras, when mutilated, exude a reddish purple fluid. A species (*Purpura paluta*) closely related to our Rock Snail occurs in Mediterranean waters and was the basis of the famous Tyrian purple dye of Roman days. Periwinkles are also found on European coasts and are exceedingly abundant on the rocky shores of England where they are sold to the poor in the large cities. This snail was introduced into American waters by way of Iceland, Greenland and the Labrador coast. Cape Cod was the southern limit of its range for many years, but now it is reported as far south as New York. Vast colonies of Periwinkles are found along the Maine coast on rocks exposed at high tide. The shell of *L. littorea* is dark brown in color, five-eighths of an inch long, thick and heavy with a sharp pointed spire and large body whorl. *L. rudis* is a smaller species

and some varieties require more sheltered places. The two species are not found together. The Limpets have flat tentlike shells and are well represented on both coasts of the United States. The Tortoise-shell Limpet (*Acmaea testudinalis*) is exceedingly common on the New England coast clinging to the rocks between tides. It ranges from the northernmost waters to New York. When cleaned the shell shows a mottled coloration of pale green, brown and white. A smaller, more fragile variety, exceedingly common along the New England coast, lives on eel-grass. It has brighter coloring — reddish brown spots on a white surface.

The most noticeable bivalve is the Common Edible Mussel (*Mytilus edulis*) which lives in colonies between tides from North Carolina to California and is also common on arctic shores and the northern coasts of Europe. It is exceedingly abundant along the New England coast, so much so that in places it blackens the shore. Great masses of these shells cover shallow, sandy and muddy flats; they are also found in gravelly situations and in pebbly stations among large rocks. The shell of this species is two and a half inches long and violet in color, but the color of the epidermis is black or deep blue. A variety found associated with the typical form has a shell that is brightly rayed in green and yellow. These mussels are attached by strong, yellow-colored fibers, the byssus, secreted by a gland in the foot.

Crustaceans are well represented in rock pools. One of the conspicuous forms is the Rock Barnacle, Acorn Barnacle or Sea Acorn (*Balanus balanoides*) that inhabits the Atlantic shores of Europe and America from

the Carolinas northward. It is so abundant that it not only whitens the rocks between tide levels with a complete incrustation of shells, but the individuals are so closely crowded together that they lose their normal shapes and become distorted and elongated. When the valves are open, the delicate, curling feet may be seen sweeping food into the hungry mouths; but at the least jar or shock the waving motion ceases and the valves close with a snap. These barnacles also incrust woodwork between tide marks, bottoms of ships etc. and cause considerable trouble. Among the crabs to be looked for are the Rock Crab (*Cancer irroratus*), the Green Crab (*Carcinas maenas*) and the Toad Crab (*Hyas coarctatus*). The Rock Crab is a crawling crab, the common crab of the New England coast north of Cape Cod. It ranges from Labrador to South Carolina, but is rare south of New Jersey. It frequents sandy as well as rocky shore, and while it is most abundant a little below tide level it is found in tide pools and between tides buried in sand or gravel, or hiding in rocky crevices. Above it is a dull brick-red color speckled over with small, brownish spots; underneath it is yellow. When the adult Rock Crab moults in the winter time, it becomes the Soft-shelled Crab of the New York market. The Green Crab is another of the common species of the Atlantic coast. It is abundant on the New England coast north of Cape Cod and in Long Island sound. Here it is used as bait but it is sold as food in Europe where it occurs along northern coasts. Besides in tide pools, it also occurs well up on the beach between tide marks and in holes or cavernous places on the shore. In color this crab is dark olive-green mottled with yellow-

green. The Toad Crab is a Spider Crab, the commonest one along the New England coast north of Cape Cod. It spreads over two and one-half inches. The body is relatively large, the legs slender and weak, and the back and legs are often densely covered with seaweed planted by the crab itself. This crab crawls over rocky bottoms in deep waters but it is abundant in shallow, rocky tide pools from the Arctic ocean to New Jersey. It forms an important part of the food of cod. Little crustaceans also are to be sought in our pools under stones and seaweed. Among these are the little Beach Flea (*Orchestia agilis*) and the Scud (*Gammarus locusta*) which resembles the former but is much larger. In both these small crustaceans the body is flattened laterally. The Beach Flea is about half an inch in length and of a brown color that much resembles decaying seaweed. When disturbed it jumps with great agility and strength. It ranges from New Jersey to Greenland. The Scud is much larger, sometimes attaining a length of one and a half inches. It is reddish or olive-green in color and has the same range as the Beach Flea. There are other species of *Gammarus,* some slate color.

Rocks and *rocky bottoms* support a great variety of life, but the character of the association, particularly between tide marks, depends upon the degree of exposure. No other habitat is subject to such a wide range of fluctuation in environmental conditions as rock beaches, and the fauna is composed largely of animals that are either small and ubiquitous, active and hard-shelled, permanently attached or with well-developed clinging organs. The Rockweeds, Common Edible Mussels, Limpets and Acorn Barnacles have shapes

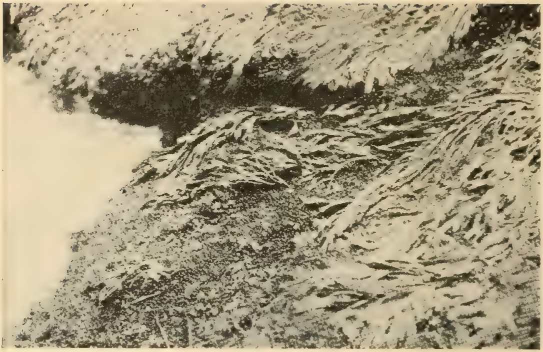


Figure 15 The seaweed *Fucus* replaced by the sea mussel *Mytilus* on a rock face exposed to wave action, Nahant, Mass. (Courtesy Wisconsin Nat. Hist. Soc.)

Figure 16 Alga-covered rock face, Nahant, Mass. No *Fucus* except where tide spurts through a narrow fissure (*f*); *Ascophyllum* (*a*) on the protected surfaces; above which is the barnacle (*Balanus*) zone (*b*). (Courtesy Wisconsin Nat. Hist. Soc.)

and methods of attachment which make them admirably suited to withstand the force of the waves. They, moreover, succumb in the order given. The Acorn Barnacle is the first to cover a clean, exposed rock surface and the last to leave it. Next to the above forms come the Periwinkles and the Rock Snails. Attached coelenterates, sea anemones and hydroids, are also well suited to a life on the rocks. The hard-shelled animals, as the crabs, are able to withstand considerable beating by the waves and by migrating downward with the tide they escape exposure to the sun. The small, ubiquitous, motile animals, including small crustaceans and worms, hide under seaweeds and in crevices when the tide recedes and thus secure protection. They occur in great abundance and become very active when the tide is in. Many attached organisms characteristic of deeper waters are brought in to the shore by the large, hard-shelled crabs that migrate back and forth. The rock beach fauna must be, and is, a hardy one. The factors that count are fixation, ability to capture food and ability to withstand exposure and changes in temperature. The animals that show the greatest development of the above characteristics have the widest distribution. The Acorn Barnacle is everywhere, therefore, because it has a firm fixation, the ability to capture food anywhere that seawater comes, and a remarkable resistance to changes in temperature. The exposure and variation in the barnacle zone are greater than anywhere else on the beach. Seaweeds are absent from this zone, but the Edible Mussel (*Mytilus edulis*) is found in crevices right to the top of the zone. The Periwinkle or Rough Winkle (*Littorina rudis*) often occurs on bare rocks above the barnacles. This form is on its way

toward a land existence. The other Periwinkle (*L. littorea*) is found in the barnacle zone in situations similar to those of the Edible Mussel. These two have almost as wide a distribution as the Acorn Barnacle. The Rock Snail is abundant where barnacles occur, for it feeds upon them.

Below the barnacle zone, along our North Atlantic rocky coasts, the brown seaweed, *Ascophyllum,* with its long, matted strands, is to be looked for. There is an abundant fauna here because of the shelter afforded by the seaweed. The Acorn Barnacle is also found here and is abundant. Hydroids are found attached to the rock or on this seaweed in protected situations; other seaweeds replace them in more exposed places. Bryozoans or Moss Animals also occur on the *Ascophyllum* and the rocks. Small crustaceans and worms are numerous. Many animals are attached to the rock under the matted seaweeds. Rock Snails are abundant; the Common Edible Mussel and Periwinkle (*L. littorea*) are everywhere; the Seaweed Snail and Limpet (*Acmaea*) are less common. The Rockweed (*Fucus*) zone is just below this. In protected bays it does not occur and on isolated wave-beaten rocks the Acorn Barnacle and Edible Mussel replace it. The most characteristic animals are the Edible Mussel, Acorn Barnacle and Limpet (*Acmaea*). Other forms that are common are the Rock Snail, Periwinkle (*L. littorea*), Seaweed Snail, Common Starfish, a sponge (*Cliona*), the Jonah Crab (*Cancer borealis*) the Hermit Crab (*Eupagurus pubescens*), etc. The zone below starts a little above low-tide mark and continues to a considerable depth. More species are found here than in any other zone. The Irish Moss (*Chondrus*) which characterizes this zone and forms a thick carpet on the

Figure 17 The barnacle *Balanus* on a vertical rock wall (Courtesy Wisconsin Nat. Hist. Soc.)

Figure 18 The periwinkle *Littorina* in a crevice just above the *Ascophyllum* zone (Courtesy Wisconsin Nat. His. Soc.)

rocks affords shelter for a great variety of animals. The animals most characteristic of this zone are the Limpet (*Acmaea*), the Common Starfish, Jonah Crab, Brown Sea Anemone, Moss Animals (Bryozoa) and the Common Edible Mussel, Periwinkle and Acorn Barnacle which are as abundant as elsewhere. Other forms more or less common at low tide are hydroids, a sponge, the Rock Snail, Seaweed Snail, small crustaceans and the Rock Crab and Green Crab. The pools in this zone add other residents such as Chitons, the Green Sea Urchin, the Horse Mussel or Bearded Mussel (*Modiola modiola*), nudibranchs or Sea Slugs etc.

The discussion above will serve to give an understanding of the character of some of the associations found on a rock beach along our shores, in this case quite typical of New England and the Massachusetts coast in particular. There is perhaps also needed, as in the case of the tide pool fauna, a general survey of the most common forms of the various groups to be searched for on rocks and rocky bottoms. The Finger Sponge (*Chalina oculata*) is dull red or yellow in color and grows on rocks or shells forming finger-shaped masses about six inches high. It is common north of Cape Cod at depths greater than fifteen feet. The Boring Sponge (*Cliona sulphurea*) is common along the shores from Cape Cod to South Carolina and is abundant in Long Island sound. It is bright sulphur yellow in color and grows in irregular masses of considerable size and fine texture. It lives on shells, completely honeycombing them. It is very destructive to the shells of oysters, clams etc. There are many littoral forms of hydroids living in the chinks and crannies of the rocks and on seaweeds. The sertularians

(*Sertularia pumila, S. argentea*) are everywhere along the coast. *S. pumila,* the most abundant of all the hydroids of the New England coast occurs in profusion on the rocks and on Rockweed and other seaweeds. The creeping stem gives rise to upright branches one or one and a half inches in height and more or less branched, with horny cups close against the stem (sessile). *S. argentea* is a beautiful species with a profusion of silvery branches on a dark stem. The colonies are often a foot or more long. This form is common from New Jersey northward. The Sea Cypress (*S. cupressina*) has the same range and is similar to the above, but the main stem is thicker and longer and the branches less crowded and subdivided. Both the Brown Sea Anemone and the Crimson and Rose Anemone occur here, as in the rocky pools; the former in sheltered crevices and under large stones; the latter on ledges covered with Rockweed and in shallow water. There is an interesting form of sea anemone which lives in shallow water in the West Indies and the Bermudas, under rocks or in crevices. It resembles a pancake, and hence goes under the name of Cake Anemone. Only one stony coral extends as far into the temperate zone as our coasts. This is the little Star Coral (*Astrangia danae*) which is found from the Carolinas to Cape Cod. It lives in clefts of rocks in small patches, sometimes two or three inches across, which look like a thin crust of lime with star-like divisions and sometimes branch. The individual is one-quarter of an inch or more across. The living animals are white so that when they are expanded the patch of coral resembles a cluster of small sea anemones. In Long Island sound this coral is abundant in-

crusting stones and shells. The Fleshy Coral (*Alcyonium carneum*) is rarely seen in shallow water, but is common on rocks at a depth greater than 20 feet. It ranges from the east end of Long Island to the Gulf of St Lawrence. The expanded coral resembles a delicate pink flower, but when this form is first brought up from the bottom it looks like an ugly, tough gelatinous mass covered with finger-shaped processes of a dull yellowish-pink color. Dead-Men's-Fingers (*Alcyonium palmatum*) is another fleshy coral, sometimes found at low-water mark, but usually in deeper water attached to shells and stones. It has the appearance of a human hand with only the stumps of the fingers left, hence the name. It is found in abundance along the New England coast. An immense type, treelike in form and measuring six feet or more in length, grows on the fishing banks off Newfoundland and is sometimes brought up with the fishing lines.

Of the worms the Shell Worm (*Serpula dianthus*) will probably attract the most attention, not only because it is so common along our coasts from Cape Cod to New Jersey, but also because of the crooked, stony white tube which it secretes upon the surface of rocks and dead shells etc. One bryozoan, the Moss Animal (*Bugula turrita*), occurs very abundantly everywhere along the coast from Maine to North Carolina, and it is so abundant on rocks below low-tide level that they appear to be covered with mossy tufts ten inches to a foot long. It also grows on piles and wharves. The tufts are erect; the lower part of the stem is orange in color, while the tufts of branches are pearly-white or yellowish. This form, like all the species of *Bugula*, has the birdlike

appendages (avicularia). In time of storm large quantities of the Moss Animal are thrown upon the beach. Another bryozoan, the Red Crust (*Escharella variabilis*), occurs on the rocks, as in the tide pools. There is only one brachiopod or Lamp Shell that lives along our northern coast, the Parchment Shell (*Terebratulina septentrionalis*) which ranges from Massachusetts to Nova Scotia. Species of this genus are found in the shallower waters of all seas. The animal lives from low tide to a depth of 300 feet or more, and is extremely abundant on rocky bottoms along the New England coast. The valves of the shell are calcareous, about five-eighths of an inch long, and there is a short fleshy pedicle attaching the animal to the rock.

Echinoderms are well represented. Many of the sea urchins, also called sea-eggs or egg-urchins, along coasts exposed to the action of the waves, live in cavities which they hollow out of the solid rock by mechanical action. A form (*Strongylocentrotus purpuratus*) related to the Green Sea Urchin occurs on the California coast in such numbers that tracts of coast are completely honeycombed and pitted with such burrows where the animals seek shelter against the surf beating against the rocks. In sheltered places the same species does not excavate. In addition to the Green Sea Urchin we also have the Purple Sea Urchin (*Arbacia punctulata*) which ranges along our coast from Mexico to Cape Cod. It is of a dark brown or brownish purple color and is common on broken rocky bottoms on rocks at low-water mark. The Purple Sea Cucumber is found from Texas to Cape Cod. The large purple form (*Pentacta frondosa*) is plentiful along the New England coast, especially Maine. A form, bright red in color (*Lopholthuria fabricii Cuvieria squa-*

mata), is found on the New England coast on the underside of large shelving rocks. The body in this species is covered with overlapping scales and granulations, and when retracted is about an inch thick and two and one-half to three inches long.

The common representatives of the crustaceans besides the numerous small crustaceans are the ubiquitous Acorn Barnacle, a large solitary species of barnacle (*Balanus hameri*) which is found on rocks below low tide along the New England coast north of Cape Cod, the Rock Crab, Jonah Crab, the Toad Crab and the American Lobster (*Homarus americanus*). The American Lobster also inhabits sandy shores. It is found from North Carolina to southern Labrador and now is most abundant off the coast of Maine. While our lobster is usually dark green in color, with red and blue mottling, blue, red or cream colored lobsters are sometimes seen. Lobsters, like crabs, go to deeper water in cold weather, but they never go to a depth of much more than 600 feet. The Spiny Lobster (*Panulirus argus*), common in the waters of the Bermudas, Florida and the West Indies, lives in rocky crevices in shallow water. It has five pairs of walking feet which lack the claws, and is therefore often referred to as the Clawless Lobster.

The species of mollusks common to the rocky shores include the nudibranchs (*Doris, Eolis*) already mentioned and a pale yellow species (*Ancula sulphurea*) commonly found on rocky bottoms off the New England coast north of Cape Cod and very abundant in the deeper waters. Then there are among the gastropods the abundant Limpets, Periwinkles and Rock Snails, also the English Whelk (*Buccinum undatum*) and the Ten-Ribbed Snail. The English Whelk af-

fects every kind of station and is as much at home at considerable depths as at low-water mark. The shell is about three inches long, marked with revolving ridges and transverse furrows and with a velvety brown skin. This species ranges from Cape Hatteras to Greenland, the Arctic ocean and northern coasts of Europe. In England and Scotland it is used as a food under the name of "whelk." Along the Maine coast it is found almost everywhere at just below low-tide level, but south of Cape Cod it lives in deep water down to a depth of 3900 feet. The Ten-Ribbed Snail (*Chrysodomus decemcostatus*) is one of the striking shells of our northeast coast. It is abundant just below low-water mark and is often found associated with the above, but not quite so common. It is fully three inches in length, yellow-brown in color and has ten ridges. This shell is one of the favorite abodes of Hermit Crabs when empty. Snails related to the Key-Hole Limpets and inhabiting our Pacific rocky coasts might be included here because the wide commercial uses of the shell in jewelry, inlaid work etc. has made them so well known. These are the Abalones (*Haliotis*), known in England and the Channel Islands as Ormers or Sea-Ears. The shell is spiral but so greatly flattened that the spiral appearance is lost. It is six to eight or nine inches long. These animals are vegetable feeders. They cling to the rocks at low tide so tenaciously that skill is required to remove them without breaking the shell. Before it is polished the outer side of the shell is rough and unattractive; within is a beautiful, highly colored, pearly luster. The shell shows rainbow colors or it may be red or very dark green. The Common Edible Mussel found on our

rocky shores is replaced on the rocks of the west coast by another species (*Mytilus californicus*) which is about the same size. The Cod Clam (*Cardita borealis*) which forms one of the foods of the cod is common on rocky and gravelly bottoms at depths of 30 to 600 feet and is found from Cape Hatteras to the Arctic, on the Pacific shores of Alaska and on the northern coasts of Europe. The shell is covered with a dark brown skin and is about one inch long and three-quarters of an inch wide and has 20 deep curved furrows radiating out from the beak. There are two interesting rock-boring bivalves found on our Atlantic coast. The Angel's Wings (*Pholas costata*) ranges from Cape Cod to South America, but is not abundant north of Hatteras. The shell is seven or eight inches long, white in color, and the suggestive shape and ribbed sculpturing give it the name. It is found in holes gouged out of solid rock which the animal makes by constantly turning the shell around. It also makes holes in wood and sometimes in hard clay like *Petricola*. In Florida it burrows deep in sand as well as in wood or rock. The other rock-boring forms (*Lithophagus*) are common in tropical oceans. They are found in the coral rocks of Florida. The animal when young bores or dissolves out a cavity within coral rocks or dead coral and remains there the rest of its life, enlarging the cavity as it grows.

The above summary covers the common, more readily recognized forms of our rocky shores. There will be found on these shores also many forms that live in deeper water and are washed in during storms.

Sandy Bottoms

The fauna of sandy beaches is composed largely of animals that burrow and with this burrowing ability is often combined a heavy body. The surface of the beaches, however, is strewn with remains of many species, usually beach-worn, that are washed out of the sands by the waves, some even carried in from great depths and distances during storms. There will be a great variety of mollusk shells, tests of crustaceans, echinoderms, worms etc. As along rocky beaches pelagic (swimming and floating) animals are an important part of the fauna. Egg cases form another class of objects to be looked for. There is the Devil's Pocket Book, the egg case of the skate; the long strings of saucerlike capsules which are the eggs of the Giant Whelks; the collarlike sandy rings containing the eggs of the Sand Collar Snail, which are called Tommy-Cod Houses by the Cape Cod children; and the Ears of Corn which are cylindrical piles of little capsules and are the eggs of the Ten-Ribbed Snail. Along the upper part of the sand beach extends an almost continuous belt composed of dead seaweed, broken shells, fragments of crabs and lobsters and a variety of débris cast up by the waves, and this sea-wrack is alive with Beach Fleas and other small crustaceans. Variations in the fauna of sandy beaches depend largely upon the purity of the sand and the proportion of mud present. The slope of the beach is also important as this affects the capacity for retaining moisture. Plants, too, modify the sand faunas considerably as there are many animals that live on the blades or among the roots of plants. Just as with the rocky shores, many zones may be recognized.

One may treat the beach under the divisions of the inner and outer beach or one recognizes such zones as the drift at high tide mark, the gently sloping beach below partly covered by high tide, the flat ripple-marked beach near the ocean, the compact arched beach below, the rapid slope beach and the gently sloping expanse of sand extending into the deeper waters. Again, animals may be treated according to the depth at which they live in the sand, as species dwelling on the surface, stratum one to two inches below the surface, stratum two to three inches below the surface etc. Such detail is beyond the scope of this chapter, and the survey below will touch only upon the commoner forms of the various groups of animals to be looked for on sandy bottoms. Descriptions are given only when the form has not been discussed before.

There are three species of sponges which may be found, two of these growing on shells that may be cast up on the beach: the sulphur colored Boring Sponge and the Red Sponge (*Microciona prolifera*). The latter occurs in shallow water from South Carolina to Cape Cod and is very abundant upon oyster and scallop shells in Long Island sound. In color it is brilliant crimson. In its younger stages it forms thin incrustations, but it branches as it grows older, sometimes having branches four inches long. The Sulphur Sponge (*Suberites compacta*) grows on sandy bottoms off the Long Island coast. It is a compact, heavy sponge, bright yellow in color with a smooth surface, rounded and nodular. After death it darkens to an ugly brown color.

Hydroids are found cast up on the beaches. Horny skeletons of large varieties are frequently washed ashore

and smaller living species often are found in their tangled masses. The sertularians are found everywhere along the coast and are among the most common objects found along the beach. Jellyfishes, which are part of the plankton of the shore waters, are found cast up on the beach, among them large forms such as the Milky-Disk Jellyfish (*Aurelia flavidula*), the Speckled Jellyfish (*Dactylometra quinquecirra*) and the Milky Cross (*Staurophora laciniata*). The Milky-Disk Jellyfish is 8 to 10 inches in diameter and may be recognized by the four horseshoe-shaped reproductive organs near the center which are yellowish white or pink in color. It is common north of Cape Cod to the Arctic ocean, but is not very abundant along the New York coast. The young are found fastened on the rocks and seaweeds of the shore. The Speckled Jellyfish occurs in the upper reaches of bays and estuaries, from Florida to Cape Cod and in some places is very abundant. It is a large form, reaching a foot and a half in diameter. The Milky Cross measures four to eight inches in diameter. It is very abundant along the New England coast north of Cape Cod, but in the spring may be found along the New York shores. The effect of the cross is produced by the mouth which is bordered by veillike frills. There is a small form that looks like a large thimble of jellylike substance, the Thimble Jelly (*Melicertum campanula*). This is an arctic form which is extremely abundant north of Cape Cod until the middle of summer, but is found farther south only in spring. One of the most striking forms that is frequently found stranded on the beach is the Sun Jelly or Sea Blubber (*Cyanea arctica*). This is the largest known jellyfish. The disk is amber colored, usually three to five feet in diameter but one specimen was found

seven and a half feet across the disk and with tentacles more than a hundred feet long. This form is found in the cold waters north of Cape Cod and is common along the New England coast. Along the Long Island coast it is found only in the spring and early summer and is of much smaller size. The anemone to be searched for in a sandy environment is the Sand Anemone (*Holocampa producta*) which is characteristic of sandy and muddy beaches from Cape Cod to South Carolina. On sandy beaches it is found buried in the sand with only the tentacles exposed, but it is also found under rocks at low-tide mark. This species is dull yellowish gray in color. It is three or four inches long and half an inch in diameter, but can contract to a length of about two inches when disturbed.

Of the brachiopods or Lamp Shells no representative is found along our northeastern sandy shore, but a Lingula-like form (*Glottidia pyramidata*) ranges from Chesapeake bay to Florida and is very abundant off the coast of North Carolina on shoals exposed at low tide, half-buried in the sand. The valves of the shell are tongue-shaped and horny. The shell is drawn down into the sand by contraction of the stalk or pedicle. A great many species of worms are inhabitants of sandy shores but only a few will be touched upon here. A relative of the Clam Worm (*Nereis virens*), which is so common on muddy beaches, is found along the Middle Atlantic coast on sandy shores. This form (*Nereis limbata*) is recognized by its small size (6 inches long) and its horny, yellow colored teeth. The Lug Worm (*Arenicola marina*) which is of economic importance because of its use by fishermen for bait, makes burrows 18 to 24 inches deep on sandy and muddy southern shores and on the west coast

of Great Britain and Europe. It can be traced by the castings at the mouths of the burrows which are such a marked feature of tidal mud flats or of sands with an underlying layer containing vegetable detritus. This worm is five to ten inches long and of a brownish green color, with 12 to 13 pairs of branched red gills. In some areas, particularly where sheltered as in estuaries, it occurs in immense numbers, varying with the food supply. The Ribbon Worm (*Meckelia ingens*) is common on both muddy and sandy beaches living beneath the ground near low-water mark, from South Carolina to Cape Cod. While a good swimmer, this is a burrowing form and, though soft, penetrates the sand with great rapidity. It is yellowish or flesh color and when full grown attains a length sometimes of 12 to 13 feet when fully stretched, though when contracted, even the largest measure no more than five feet. The Pink Ribbon Worm, (*M. rosea*) is much smaller, never more than ten inches long and a quarter of an inch wide. It lives in sand near low-water mark. It is dull red or flesh colored, but the body is slime-covered and the sand adheres tenaciously. There is also a dark flesh colored or purplish worm (*Tetrastemmea arenicola*) living in sand at low-water mark. This form is slender, cylindrical and four to five inches long when extended. The Four-Jawed Worm (*Euglycera americana*) is a stout, active worm, one foot long and a quarter of an inch wide, which has the appearance of a reddish iridescent earthworm. It is common in our beaches between tide limits. The so-called Blood-Spot (*Polycirrus eximius*) is another worm that lives on our sandy beaches immediately below low-water mark. It is about four inches long and the forward half of the body is blood-red. The blood red tentacles that surround the

mouth are its most marked characteristic. The Fringed Worm (*Cirratulus grandis*) too, is common in burrows in sandy and gravelly beaches at low-water mark. The body is dull, brownish yellow in color and there are a large number of long, red or orange colored threads, the gills, arising from the sides of the body and especially numerous around the head. These gills are thrust out into the water above while the worm is safely hidden in its burrow. There is a worm-shaped creature known as the Acorn Worm (*Balanoglossus kowalevskii*), which is found in shallow water below low-tide level from Massachusetts bay to the Carolinas. It lives in tubular burrows about five inches long in sandy beaches. This is not a worm, however, but is a more highly developed form belonging to the chordate phylum with the ascidians.

Echinoderms are well represented. The two common starfishes, already discussed, are found on the sandy beaches off our coasts. A large starfish, the Giant Starfish (*Pentaceros reticularis*), is found on sandy bottoms off the Florida coast and the West Indies, usually at depths greater than ten feet. This is the largest starfish, having a disk five inches thick and one and a half feet in diameter. Other species of starfish occur on our eastern and western coasts, some of them many-rayed, such as the red and purplish, twelve to fifteen-armed *Crossaster* common along the New England coast. Among the urchins are the Sand Dollar (*Echinarachnius parma*) which swarms upon sandy bottoms from New Jersey to the Arctic and Pacific, and is cast ashore by the thousands during every great storm. This form is three inches in diameter, flat with a rounded edge, and covered with short brown spines. An indelible ink is obtained through pounding up Sand Dollars in water. Though

some species occur in deep water, Sand Dollars and Cake Urchins are found mainly in sand considerably below the low-water mark. Some species thrive when they are subject to the exposure of open sandy beaches. The Greenish Blue Cake Urchin (*Mellita testudinalis*) is very abundant in shallow water from Cape Hatteras southward and is even found as far north as Cape Cod. The Heart Urchins found along our eastern coast are yellowish white or brown in color. One species (*Schizaster fragilis*) is one and a half by two inches in size, one inch thick and brown in color, and lives in deep waters. In the warmer waters of the California coast, those of Florida, the Gulf of Mexico and West Indies, there are species of reddish or reddish gray color. The Heart Urchins have heart-shaped, or thick elliptical bodies. There are a few littoral species, but most of them bury themselves in sand or mud and live in deep water. The Stinging Urchin (*Diadema setosum*) is abundant along the Florida coast and in the West Indies. It is seen in clusters on sandy bottoms and is also found on the reefs. It is a velvety, jet-black in color, grows to four inches in diameter and has sharp-pointed, black spines up to four inches in length which penetrate the skin if seized and break off, inflicting a painful sting. The Brittle Sea Cucumber (*Synapta inhaerens*) is to be looked for on both sandy and muddy beaches from the Carolinas to Cape Cod and also on the coasts of Europe. It lives in sand tubes. At first sight it looks like a worm. It is translucent with five white lines extending down the length of the body which is highly contractile, but which extended has a length of a foot and a diameter of an eighth of an inch. Under unfavorable conditions it can break itself to pieces by muscular contraction.

Mollusks are to be found in numbers on sandy bottoms. Among the snails are found the Ten-Ribbed Snail and English Whelk, also found on rocky bottoms. The Sand Collar Snails and Moon Shells are numerous and the very striking Giant Whelks are to be looked for here. The Sand Collar Snails are recognized by their large size, light yellowish brown or bluish white color, blunt, rounded spire and simple, rounded opening with sharp-edged lip. In the Northern form (*Lunatia heros*) the umbilicus or central cavity of the body whorl is open, in the southern form (*Neverita duplicata*), closed by a plug or callus. The Northern Sand Collar Snail ranges from Virginia to Labrador and is largest and most abundant south of Cape Cod. It is one of the most characteristic species of the New England and New Jersey littoral fauna and is very abundant along the Long Island shores. In summer the egg capsules are common surrounding the shell. The Southern Sand Collar Snail is also very abundant off the coasts of Long Island and New Jersey, but its range is from Yucatan to Massachusetts bay. The Moon Shell (*Natica clausa*) is a northern species which is fairly abundant on the Maine coast. The shell is half an inch long and livid white to light brown in color, and there is a calcareous operculum which identifies it at once. Other species of this and related genera are found on southern and western coasts. The Giant Whelks are the largest coiled shells found north of Cape Hatteras. These two species, the most characteristic mollusks of the American Atlantic coast, are both exceedingly common in sandy shore stations from Cape Cod to the Gulf of Mexico, and are especially abundant along the

New Jersey coast and in Long Island sound on sandy and gravelly bottoms. They are pear-shaped and about six inches long. The Knobbed Whelk (*Fulgur carica*) is characterized by knoblike protuberances around the shoulder of the body whorl; the Channeled Whelk (*Sycotypus canaliculatus*) lacks these, but has a deep channel at the suture of the spire. Both prey upon other mollusks and are destructive to clams and oysters. Another characteristic snail that is cast upon the beach looks like a worm with a calcareous covering (*Vermicularia spirata*). It starts like a gastropod shell, then the whorls become separated and seem to wander in an aimless way. Many of these shells are found grouped together in an inextricable mass. These forms inhabit shallow water from New England to Florida. The shells are ashy white or rufous. The Oyster Drill (*Urosalpinx cinera*) is also washed in from the oyster beds. There are several species on the eastern coast of the United States. This species has a wide range from Florida to Cape Cod. Its original home was in Chesapeake bay and it was transplanted with the oyster spat. The shell is dingy gray in color; a dozen or more riblike undulations cross the whorls which also bear numerous revolving striae; the spire is high and the anterior canal is produced and of a yellowish brown color within. Boat Shells (*Crepidula*) are cast upon the beaches attached to dead shells, horseshoe crabs, stones etc. The largest species (*C. fornicata*) is exceedingly common on the Atlantic coast, ranging from the West Indies to Nova Scotia. They are also known as "deckers" or "slipper limpets," and are degenerate, scalelike snails that fit closely to the surface to which they are attached, made

fast by a stony cement secreted by the foot. The shell is decidedly convex and of a gray, horny color with faint reddish brown flecks over the surface. The shape and the shelly partition inside give these shells their popular name. The Sand Flat Snail (*Nassa trivittata*) is also found on muddy and stony bottoms, extending into water about 240 feet deep. It ranges from Florida to Nova Scotia, and is most abundant on the Massachusetts coast north of Cape Cod and on the sand flats of Long Island sound. It is a small shell, five-eighths of an inch long, and is carnivorous, boring through the shells of other mollusks. It resembles the Mud Flat Snail, but may be distinguished by the sharp spire and regular granular surface. There are many other snail shells to be found on our sandy beaches, but those mentioned above are found most commonly. One of the most graceful and one of the larger shells of our eastern coast, a deepwater dweller occasionally washed up on the beach, is Stimpson's Sipho (*Sipho stimpsoni*). This form is almost identical with one of North European waters and for a long time was thought to be the same species. It is not found south of Cape Cod and ranges north to Newfoundland, living in waters 20 to 100 feet deep. The shell is three to five inches long, with a high spire and seven to eight whorls with simple sutures. The epidermis is thick, horn colored and sometimes velvety, but the shell beneath is pure white. There are four or five exceedingly common species of Ladder Shells and Wentletops (*Scala*), all found on the beach after a storm or they may be dredged in shallow water near the shore. One species ranges from Cape Cod to Florida; some from Cape Hatteras to New England

(*S. lineata*); another (*S. groenlandica*) is an arctic species that extends south to New England. These shells get their name from a peculiar scheme of decoration that can not be mistaken when once noted. They are usually pure white with rounded whorls. The whorls are crossed at even distances by greatly elevated, smooth ribs which give the basis for the popular name. Scaphopods or Elephant's Tusk Shells are, strictly speaking, not littoral, as they range into deep water. Two species (*Dentalium dentale, Entalis striolata*) are exceedingly common in the New England coastal waters at very moderate depths and are sometimes cast upon the beach during storms. They are one inch to an inch and a half long and are shaped like elephants' tusks, slightly curved, white, round, hollow tubes. They live buried in mud and feed on infusorians and other microscopic organisms.

Bivalves are as characteristic of sandy bottoms as the snails. There are several clams that are common, some of them already familiar. The Soft-Shell Clam (*Mya arenaria*), often called the "long clam" or "nanninose" is the common soft-shell clam of New England and is highly esteemed in the market. The shell is quite thin and brittle. This mollusk is found between tides in sandy, muddy, pebbly or even rocky ground if it can find material into which it can burrow and hide, and it lives in the burrows with the long, extensible siphon pointing upward. It is common in sheltered banks of bays and estuaries between tide limits. This clam ranges from the Carolinas to the Arctic and also occurs on the northern coasts of Europe. Along the Maine coast it is gathered and sold for bait to the Banks fishermen. The Round Clam (*Venus mercenaria*), also known as the

Little Neck Clam or Quahaug, is the common hard-shelled clam of our markets. It ranges from Yucatan to Nova Scotia, but is common only from the Carolinas to Cape Cod. It is most abundant in shallow bays and estuaries where it lives below low-tide level in muddy bottoms. In open, deeper bays and along the open ocean it is found in sandy stations. The shell has a grayish or dull brownish gray skin and shows quite regular and deep rings of growth. The Surf Clam or Hen Clam (*Mactra solidissima*) lives in sand near the margin of the water, often upon an exposed, open coast. It is one of the commonest, if not the very commonest, of the large bivalves found on the beaches of New England, Long Island and New Jersey, perhaps the first shell a collector will find on an open sandy beach north of Cape Hatteras. It lives from low water to a depth of about 60 feet. The shell is heavy, four inches wide by six or seven inches long, with a horny, light brown skin. This clam can dig rapidly, but it lives close to the surface and is often cast ashore by storms. It ranges from the Gulf of Mexico to Labrador. The Sand-bar Clam (*Siliqua costata*) lives within loose sandy beaches and bars in shallow water below low-tide level, and it is found only where the ocean water is pure. It ranges from Nova Scotia to the Carolinas. The shell is an inch and a quarter long by three-quarters of an inch wide and is covered with a rich brown skin. The foot is very powerful, but it burrows only a short distance beneath the sand. Occasionally it comes to the surface and skips about by means of the powerful foot and the flapping motion of the valves. The Swimming Clam (*Solenomya velum*) burrows into both sandy and muddy beaches and like the Razor Clam and Sand-bar Clam prefers pure ocean water. The foot of this clam

can be expanded at the apex into an umbrella shape, and through this expansion the clam swims backwards, hence the name. It can swim a considerable distance. The shell is three-quarters of an inch long, thin and flexible, of a rich brown color with yellow lines radiating from the hinge. It ranges from North Carolina to Nova Scotia. The Angel's Wings which burrow in wood, rock or even clay banks, elsewhere, burrow deep in sand along the Florida coast. The shell of another borer will be found washed up on sandy beaches. This is the Ship-Worm (*Teredo navalis*). It is wormlike in form with a small bivalve shell at the end, and it owes this form to its habit of burrowing into any sort of wood except palmetto or teak. This form is abundant along our shores and also on the coasts of Europe. It has done great damage to the dikes of Holland. There are many forms of these boring mollusks in southern waters. They are exceedingly destructive. Submerged timbers are burrowed and soon rendered useless; also ships, piles of wharves, buoys etc. come in for their attacks. In temperate waters these borers sometimes attain a length of six inches, but in tropical waters they have been found with a length of ten feet. The Razor Clam (*Ensis americana*=*Solen ensis*) is a common species upon the New England and New Jersey coasts on sandy beaches or sandy bars where the water is not brackish. It is found from Labrador to the Florida Keys. It is very palatable, but is practically impossible to capture as it burrows very rapidly into sandy beaches when disturbed. The shell is about six inches long and one inch wide, and there is a long muscular foot through which the rapid burrowing is accomplished. The Razor Shell (*Pinna muricata*) is very abundant in Florida waters, often found associated with

another species upon muddy or sandy shores of bays. It is a relative of the mussel family. It extends as far north as the coast of North Carolina, but is common in shallow water of the sandy shores of the West Indies and Florida. The valves are fan-shaped with wide sharp-edged margin and sharp-pointed apex. The animals attach themselves by a byssus to rocks beneath the sand, and their abundance and sharp edges render wading in places almost impossible. Other shells to be expected on a sandy beach are the cockles, of which there are a number of species occurring on both the east and west coasts. The Large Cockle (*Cardium magnum*) is one of the largest and finest cockles of the east coast of the United States and probably one of the finest in the world. The shell is four inches long by five and a quarter inches high, of almost perfect heart shape with 33 to 37 regularly disposed, radiating ribs and regularly crenulated margin. The color is yellowish brown with transverse rows of chestnut color in lines or spots. This species buries itself in soft semiliquid sand and is left exposed and alive at very low tide. It is abundant on Florida beaches. There are several other species in Florida waters and on the Pacific coast. The Iceland Cockle (*C. islandicum*) is a cold-water species that is found along the New England coast. It ranges from the Arctic to Cape Cod and does not occur south of the cape. The shells grow up to two inches in length and have 36 to 38 sharp, three-sided radiating ribs with rounded furrows between. The epidermis is yellowish brown and bristles into a sort of a fringe at the sharp edge of the ribs. A smooth form (*C. mortoni*) extends up to Cape Cod and is abundant in Long Island sound. It also occurs in Florida. At Martha's Vineyard and the north shore of

Long Island it has been reported as occurring in soft ground even above low-tide mark near the mouths of creeks. The largest of these cockles has a height and length of one inch. There is a smaller species with 26 slightly rounded ribs and less than one-half inch in its largest diameter. This is a cold-water species and is very abundant, scattered everywhere along the coast from New York northward. It is known as "small fry" among the cockles and serves as food for fishes. The Ark Shells (*Arca*) are another type of shell that are cast up on beaches in numbers to attract attention. They are solid trapezoidal or rounded shells with a tendency to have strong, radiating ribs. The Ponderous Ark (*Arca ponderosa*) is the most prominent Arca upon our Atlantic coast, especially south of Virginia. South of Cape Hatteras it is cast up on beaches in numbers beyond computation. The shell is two and one-half inches long and two inches high, very heavy and solid, with 25 to 28 ribs. In life the shell is covered with a heavy, coarse, velvety epidermis, almost jet-black in color. The Bloody Clam (*Arca pexata*) is an exceedingly common species found on the beaches of Long Island sound and along the coast of New Jersey. It is common under stones or on gravelly beaches. The shell is one and a quarter inches wide, with 32 ridges radiating from the beak and there is a rough, brown skin. This clam has red blood, hence the name. A small form, the Little Macoma (*Macoma balthica*), is of interest because of its wide range along our shore and in the waters of northern Europe. It is exceedingly common along our coast from Maine to Georgia. The Little Macoma is plentiful in all sandy and muddy bays and in the Hudson river above New York. It is dingy in color, covered with a dirty looking,

thin epidermis and measures up to an inch or so in length. Other species are also found buried in sand. There are many forms that do not necessarily inhabit sandy beaches the shells of which are cast up on the sand beaches. Among these are the *Petricola* that bores in clay beds and is washed out of its burrows by the surf; the Horse or Bearded Mussel which is extremely common on all beaches north of Hatteras, the northern coast of Europe, Alaskan Waters and Puget Sound, although it is not a shallow water form but is found attached by its byssus usually on gravelly bottoms and in crevices of rock below low-tide level; the Chestnut Astarte (*Astarte castanea*), of cold-water range, which lives along the New England coast in deeper waters and after a storm is frequently cast upon the beaches where the small shells, thick and heavy for their size (one inch by one inch) and with a thick, chestnut colored epidermis, soon attract attention; the Atlantic Wing Shells (*Avicula atlantica*), the reddish brown, obliquely oval shells with long winglike extension washed up on the Florida beaches attached by their byssus to large algae; the Jingle Shells (*Anomia simplex=glabra*) so called from the ringing sound they make when waves beat upon a beach strewn with them; and the Scallops (*Pecten*) many species of which live along our coasts and are found washed up on the beaches. Of the Jingle Shells, *A. simplex* is the commoner large form of the New England coast, one to three inches in diameter, irregular in shape and with the surface variously undulated. Thousands of these valves are cast up on the beaches from the West Indies to Cape Cod. It is found as far north as Cape Sable but it is rare north of Massachusetts bay. This is a shallow-water form, not living at a depth of more than 70 feet. There is a large

hole near the apex of the lower valve through which extends a stout stalk by which the shell is fastened to some shell or other body by a byssus. The shells are scalelike and greenish yellow in color from which they are also known as Scale Shells or Gold Shells. Of the scallops the Common Scallop or Beaming Scallop (*Pecten irradians*) is the true scallop of the Boston and New York markets. It lives at its best in shallow bays and harbors where the bottom is apt to be sandy or where it is covered with eel-grass. The valves are rounded, two and one-half inches in length and width, with normally 19 ribs, and the shell is flattened at the hinge forming a pair of equal ears. In color the shell is blackish horn to ashen gray with a shining interior. This species is exceedingly abundant. Its metropolis is Cape Cod. It is rarely found north of Provincetown and has no range north of Boston. It is abundant on the New Jersey coast and in Long Island sound, particularly near the eastern end. South of Cape Hatteras another species (*P. dislocatus*) replaces this one. There are a number of southern species and several beautiful species occur on the Pacific coast. The Arctic or Northern Scallop (*P. islandicus*) is a northern species belonging to Newfoundland. It extends into the Arctic region and is found on the northern coasts of Europe. Valves of this shell are cast up on New England beaches, but they are very rarely found south of Cape Cod. Off the New England coast it is quite common at depths of 150 feet and more, since, like many northern forms, it finds its proper environment in deeper waters farther south. The shell of this species is light orange to reddish brown in color, has a scaly skin, 50 to 100 shallow ridges and irregular ears. The largest shells are about three inches long and three and one-half

inches high. The Magellan Scallop (*P. magellanicus=tenuicostatus*) is the largest of the species of the east coast, attaining a length and height of five to five and one-half inches. Its color is reddish to brown or ashen and, as in the preceding species, one valve is flatter, smaller in size and lighter colored. The shell is marked with numerous radiating striae which gave the name to the North Atlantic form which later proved identical with *P. magellanicus* of Patagonia, giving a long range to the species. North of Cape Ann it is of common occurrence in moderately deep water. This scallop is eaten along the Maine coast where the deeper bays and arms of the sea constitute its favorite resorts.

Among the smaller crustaceans of the sandy beaches are the Beach Fleas (*Orchestia, Talorchestia*) and the Scud (*Gammarus*). The Beach Fleas live in the daytime under the masses of seaweeds thrown up on the beach and construct burrows in the sand under the débris. These little creatures are beach scavengers, devouring decayed seaweed. The Scud lives under stones and *Fucus* at and near low-water mark. The other crustaceans characteristic of sandy beaches are the already described Green Crab and Rock Crab, the Lady Crab or Sand Crab (*Platyonichus ocellatus*), the Ghost Crab (*Ocypoda arenaria*), the Fiddler Crab (*Uca pugilator*), the Common Shrimp (*Crangon vulgaris*) and the Horseshoe Crab or King Crab (*Limulus polyphemus*). The Ghost Crab ranges from Brazil to New Jersey. It digs burrows three feet deep into sandy beaches. The young are found on the hot sandy beaches along the southern coast of Long Island, but they probably do not survive the winter. The shell of this species is dull yellowish white in

color and almost rectangular in shape, about two inches wide and not quite so long. The eyes are stalked and one claw is twice the size of the other. These crabs are fairly inactive during the day but swarm over the beaches at night and as they are seen flitting over the sand in the moonlight the appropriateness of their name is apparent. The Lady Crab or Sand Crab is common on sandy bottoms from Cape Cod to Florida. In color it is a delicate greenish yellow profusely spotted with purple-colored rings. The body measures about two and one-half inches long by three inches wide. The claws are powerful and armed with jagged teeth, and the hind legs are paddle-shaped and very effective in swimming. The Fiddler Crabs are so called because the males have one claw greatly developed which with the small claw gives the effect of a bow and fiddle. For the most part they inhabit salt marshes or live on muddy banks above high tide where they riddle the ground with burrows into which they quickly rush when disturbed. They live far up estuaries and along the mouths of rivers even where the water is quite fresh. The eyes of the Fiddler Crabs are mounted on movable eye stalks. They are plant feeders. Of the three common species of the Eastern coast of North America one (*Uca pugilator*) lives on sandy as well as muddy flats and beaches near high-water mark where the sand is compact and somewhat sheltered. It digs burrows in such beaches from Cape Cod to Florida. This species is recognized by its rectangular outline and the highly polished surface of the back of the shell. The Common Shrimp is found on both our coasts and ranges from North Carolina to Labrador and Alaska to California. It is

especially abundant on the sandy shores of New England north of Cape Cod and also farther south in Chesapeake bay. The King or Horseshoe Crab is not a true crab, but is related to the spiders and scorpions and extinct eurypterids. The adult animal is about one foot broad and two feet long. There is a crescent shaped, domelike shell over the head and trunk with two furrows along the sides of the back. The abdomen ends in a long sharp movable spine. There are large lateral eyes and two small median eyes. In appearance the head region resembles that of the long extinct trilobites. The Horseshoe Crab ranges along the Atlantic coast from Maine to Yucatan, and lives on sandy and muddy shores below low-water mark where it burrows beneath the surface. There are few existing species of *Limulus,* one on our coast and several on the coast of Asia.

Muddy Bottoms

The deposition of mud implies shelter of some kind, such as estuaries, inlets, mouths of creeks etc. Muddy bottoms are inhabited by a considerable number of species that find their true home in such localities, such as burrowing and tube-dwelling species. Then there are some forms that crawl or swim about over the surface or conceal themselves in the superficial layers of mud. A variety of crustaceans, especially crabs, occurs here; mollusks, especially bivalves, are abundant and there are numerous species of burrowing and tube-dwelling worms, some occurring in great numbers. Muddy bottoms vary in their faunas according to their situations, that is, whether in estuaries, bays or sounds or along open coast. Mud

flats, just as sandy or rocky beaches, may be, and have been, divided into a number of zones each with its characteristic life. Near the top of a mud beach there may be rocks and boulders. Seaweeds are practically lacking though there may be a few stunted specimens. The Acorn Barnacle and Periwinkles (*Littorina littorea*) may be abundant on the rocks, and crabs, such as the Green Crab, may be found among the stones. Below the bouldery zone one may find a sandy mud with clams such as *Mya arenaria,* both young and old, in abundance. The Acorn Barnacle, Edible Mussel and Periwinkle also live on the stones here. Worms, such as the Clam Worm, are found under the stones and certain crabs are common everywhere. This area will gradually grade into the typical muddy areas. Then there are zones where the eel-grass is scattered and other zones where there is a thick growth of eel-grass; there are many animals that live on and among the eel-grass; several species of snails, some of them very delicate species; worms (*Spirorbis*); compound ascidians in jellylike masses; hydroids; clusters of shelly or horny bryozoans; small crustaceans (for example, isopods); flat-worms etc. Scallops (*Pecten*) are found at the base of the plants and the Common Prawn has its true home here and occurs in large numbers, swimming about freely. Also to be looked for are the Edible Crab, Mud Crab, Hermit Crab, Common Shrimp and Green Shrimp. The Common Shrimp is less abundant where the eel-grass is on sandy bottoms. The Green Shrimp is often abundantly associated with the Common Prawn.

Just as with the other associations a survey will be given of the fauna to be searched for where the bot-

toms are muddy, and, again, only those forms will be discussed which have not previously been touched upon. Among the anemones the Sand Anemone found on sandy beaches is also characteristic of muddy beaches. Hydroids and bryozoans and ascidians occur on the eel-grass. Flat worms (planarians) are also found on the eel-grass. Among the many species of worms are polychaetes, mostly sedentary forms that have tubes, though many burrow in the mud. The Clam Worms (*Nereis virens*) are common on muddy beaches and in shelly sand where they live between tide levels in burrows lined with mucus. These worms are found from New York northward. These are the giants among the polychaete worms, very active and voracious, feeding on other worms, crustaceans etc. At night they leave their burrows and swim about freely. They are of a dull, bluish green color, showing some iridescence, and often measure 18 inches or more in length. The Lug Worm, discussed above under sandy beaches, is very characteristic of muddy beaches. The Red Thread (*Lumbriconereis tenuis*) will be found in almost any of our muddy beaches. The mud is infested with these slender, threadlike worms of a deep dull-red color and about a foot long. They are very fragile and are not easy to dig out unbroken. Another species (*L. opalina*), the Opal Worm, is also abundant in muddy beaches from New Jersey northward. It grows to a length of 18 inches and is one-eighth of an inch wide, is ringed and each ring is provided with a pair of bristled feet. In color it is a rich bronze and opalescent colors play over the surface. The Tufted Worm (*Amphitrite ornata*) is abundant from Cape Cod to New Jer-

sey and lives in sand and gravel as well as muddy beaches at low-water mark where it constructs a U-shaped tube of mud particles fastened together with mucus. It is 12 to 15 inches long, flesh-colored, reddish or brown and is provided with two rows of bristles on the sides of each segment. The head end is provided with blood-red treelike gills and flesh-colored tentacles which spread out over the ground in all directions, constantly expanding and contracting, while the worm remains in the tube. The Sea Mouse (*Aphrodite aculeata*) is a remarkable worm, oval in shape, with a length of about three inches and a width of about one-half inch. It is found in muddy beaches below low-water level from Long Island northward and along the northern shores of Europe. The head is provided with feelers and the legs with short, stiff bristles, brown in color. The skin is of a dull brown color but the numerous hairlike bristles that cover the sides of the body show a brilliant green, red or yellow iridescence.

Among the echinoderms, starfishes, brittle stars, sea urchins and sea cucumbers are represented. The Mud Starfish (*Ctenodiscus crispatus*) is abundant upon muddy bottoms from Cape Cod to the Arctic ocean, but it lives at depths greater than 100 feet, has short blunt arms and it looks like a five-rayed cake. This starfish is about two and three-quarters inches in diameter and of a dull ocher-yellow or slightly greenish color. The common Green Starfish (*Asterias arenicola*) inhabits mussel and oyster beds. This form ranges from Massachusetts bay to Northern Florida. It is found on the northern shores of the Gulf of Mexico and is rare in sheltered places along the Maine coast. It is very common in Long

Island sound and along the shores of Long Island from low water to 15 fathoms. The Brittle Starfish, *Amphipholis elegans*, ranges from the New Jersey coast to the Arctic ocean, the northern coasts of Europe to the English channel. It inhabits a depth from low water to 60 fathoms in places. The Purple Sea Cucumber is found on muddy bottoms and also the Heart Urchin. Most Heart Urchins inhabit deep waters.

Of the mollusks, the gastropods are less abundant than the bivalves. The Mud Flat Snail (*Nassa obsoleta*) is a small snail, but is the most abundant shell of any considerable size from Cape Cod to the Gulf of Mexico. It ranges to Nova Scotia but is rare north of Cape Cod. It fairly swarms in sheltered muddy reaches about low tide. Along the New Jersey flats the little pools left by the tides are sometimes so crowded with these snails that they have to crawl over one another. It is most abundant on the mud flats of Long Island sound which it literally covers over wide areas. The Mud Flat Snail often lives in brackish water and frequents all the inlets between Cape Cod and Hatteras. There are other species on the Florida and California coasts. This form drills holes in other shells but is itself preyed upon by young hermit crabs that live in the shells after devouring the animals. This snail has a black shell with a shining black interior, though the shell is usually covered with mud and seaweed. The spire is blunt, but in older individuals the apex is apt to be broken away. Another snail, one of the Littorinas (*L. minuta*), is a tiny form that occurs in vast numbers and serves as food for fishes and aquatic birds. Many of the gastropods of the mud bottoms of our coasts are northern species. Among other forms, especially to be looked for on muddy bottoms off open

coasts, are the English Whelk, a variety of the Sand Collar Snail (*Lunatia heros*), species of Boat or Decker Shells. South of Cape Cod, in shallow water of muddy bays and well-sheltered places, the little Bubble Shells (*Haminea solitaria*) may often be found in considerable numbers. The shells are very small, thin and fragile, shining bluish white or brownish in color. There is no spire, the aperture is as long as the shell, which is marked by revolving grooves across which the irregular growth lines cut. Related species of this form are found on the Florida and California coasts. The Oyster Drill is found associated with the oyster beds. The Elephant's Tooth Shells which are found cast up on beaches during storms range from moderate to deep waters and live buried in mud.

Many of the bivalves are of the same species as those inhabiting sandy bottoms, such as the Soft-shell Clam, the Quahaug, the Razor Shell, the Swimming Clam, Angel's Wings, Common Edible Mussel, the little Macomas etc. Also are found the American Oyster, Ribbed Mussels, species of Scallops, the small Ledas, Yoldias and Nut Shells. Perhaps the mussels and oysters are the most conspicuous forms of muddy bottoms. The Edible Mussel grows in patches, "beds or banks," of considerable extent on the muddy bottoms of bays and sounds, and it also occurs on open coasts. The Ribbed Mussel (*Modiola plicatula*) is a brackish-water species found between tide limits which ranges from Nova Scotia to Georgia. It inhabits tidal waters of streams, sheltered muddy reaches among reeds and tidal flats, and there is probably no muddy reach of land, exposed at low tide, between Maine and the Carolinas which is not occupied by this species. There are other species of mussels along

our southern and western coasts. The American Oyster (*Ostrea virginica*) ranges from the Gulf of St Lawrence to Texas and thrives best in shallow bays and estuaries where the water is apt to be brackish. The rough, shaggy and unlovely shells are quite familiar. They are attached by the lower valve to rocks or some other firm anchorage by a secretion of the mantle. Oyster beds are generally planted on bottoms originally muddy. There are certain forms associated with the oyster beds in brackish waters. Attached to the oyster shells are the Boat Shells, Jingle Shells, the hard sandy tubes of the worm Sabellaria, calcareous tubes of the worm Serpula, hydroids, bryozoans, the common Red Sponge etc. The Oyster Drill is found here, of course. The Edible Mussel frequently occurs attached to oysters and when in large numbers they are very injurious. Another Mussel (*Modiola hamata*) is sometimes found in oyster beds. One of the Hermit Crabs (*Eupagurus pollicaris*) is abundant upon oyster beds. The Quahaug or Little Neck Clam is most abundant in shallow muddy bays and estuaries near low tide level. It is able to burrow to a slight depth, but often lies on the bottom. The Soft-shell Clam, too, lives on muddy bottoms between tides, where it can find material in which to burrow and hide. It is common in sheltered banks of bays and estuaries between tide limits. It lives in the burrow with the long extensible siphon pointing upward which at low tide it retracts. A very interesting species with a mud habitat is a boring form, *Petricola pholadiformis.* Along the New Jersey coast, and especially around Atlantic City small patches of clay or a hard tenacious mud are found along the ocean's edge. These mollusks burrow in this clay or mud and are washed out of the burrows by the surf and cast upon the

sandy beach. The shell has a length of one and a quarter inches to two and one-half inches and a width of one-half to three-quarters of an inch. It is dull white, ornamented with transverse ribs, of a thin chalky texture and gaps widely at the posterior end. A *Petricola* (*P. carditoides*) of the Californian coast has similar habits, but bores into soft rocks instead of clay. The little Nut Shell (*Nucula proxima*) is the common Nut Shell of the Atlantic coast to North Carolina, and also occurs in western Florida. It is the commonest of several species found along the New England coast where it exists in countless thousands in all the bays and harbors, in muddy or pebbly situations near the shore. The shell is a quarter of an inch long, has a light olive epidermis and nacreous interior. Another species, the Thin Nut Shell (*N. tenuis*) is found northward from Maine and along all the coast of northern Europe. It is about as big as a grain of corn, the shells are thin with a bright green epidermis. There are a few other species found on our colder coasts, and also in deep water from California to Alaska. A larger shell than the Nut Shell is the Finely-grooved Leda (*L. tenuisulcata*). The shell is about an inch long and narrows to a blunt gaping point. There is a light greenish epidermis and the interior of the shell has a pearly luster. This species is found in muddy bottoms in shoal water on the New England coast and northward. With this species, in the same situations, along the New England coast is found the File Yoldia (*Y. limatula*) which ranges southward to Cape Hatteras and is found on the Pacific coast and the coast of Norway. The shell is one to three inches long and the valves narrow posteriorly. There is a glazed green epidermis and the interior of the shell is light bluish and pearly. The Broad Yoldia

(*Y. thraciaeformis*), shaped like the blade of an axe, is also found along the New England coast, Long Island sound and southward. The shell is two and one-half inches long with a height of one and one-half inches and has an oblique wavelike rib. The epidermis is dark olive-green. Other species occur on our Northern coasts, and on the Californian and Alaskan shores.

Crustaceans are well represented on muddy bottoms. Among them are the Common Prawn, the Mantis Shrimp, the Feather-footed Shrimp, the Horseshoe or King Crab, the Blue or Edible Crab, Spider Crabs, Hermit Crabs, the Fiddler Crabs and the Mud Crabs. The Blue or Edible Crab (*Callinectes sapidus*) is the common edible crab of the Atlantic coast, ranging from Cape Cod to the Gulf of Mexico. In the south it is known as the Sea Crab. It inhabits muddy shores and is common in shallow bays and estuaries where the bottoms are muddy and covered with eel-grass and the water may be brackish. They retire to deeper waters in the winter time. This crab sheds its shell once during the summer, remaining soft for a few days, and it is then the "soft-shelled" crab of our markets. The last pair of legs of this crab are paddle-shaped, modified for swimming, and it may always be recognized by the sharp spire that projects outward on each side of the body. It may attain a width of six inches. Very closely related forms occur on the African coast, along our Pacific coast and in the West Indies. The Common Prawn (*Palaemonetes vulgaris*) is especially abundant on muddy bottoms in shallow brackish water. It has a range from Massachusetts to Florida, but is rare north of Cape Cod. It grows one and one-half inches long and is distinguished from the Common Shrimp by the sharp-pointed, saw-edged spine that pro-

jects between the eyes, more delicate feelers and slender legs. The Feather-footed Shrimp is a small, brown, translucent creature about half an inch long that is distinguished by its large eyes, spines along the sides of the body and feathery hairs on the legs and antennae. It is likely to occur in large swarms in shallow muddy or grassy places and is most abundant along our coast in the winter time. The Mantis Shrimp (*Squilla empusa*) is so named because of the resemblance of its claws to those of the Praying Mantis. It lives in long, winding, muddy burrows below low-water level, ranging from Florida to Cape Cod. This creature grows ten inches long. Other species are highly esteemed for food in the Mediterranean and tropical Pacific. The Mud Crabs (*Panopeus*) are small dark olive-brown crabs which extend in their range from the tropics to Massachusetts bay. As their name implies they have a fondness for muddy shores and live under stones or in moist burrows within muddy banks or marshes. The common Mud Crab of Long Island (*P. herbsii*) ranges from Brazil to Rhode Island. It grows one and a half inches broad. There are three species of Fiddler Crabs (*Uca*) common on our eastern coast. The species found on sandy beaches (*U. pugilator*) also inhabits muddy beaches. Another form (*U. pugnax*) lives in salt marshes, completely riddling the muddy banks with holes. It extends from Provincetown, Massachusetts to Georgia and a variety is abundant in the West Indies and Gulf of Mexico. The holes are two or more feet in depth. The largest of our Fiddler Crabs (*U. minax*), recognized by the red spots at the joints of the legs, ranges from New England to Florida and digs burrows along the banks of rivers or brooks where the water is only slightly brackish or even fresh.

Miscellaneous Associations

There are various associations which it might be well just to touch upon. One of the very interesting ones is the association of the *wharf piles, bridges, floating timbers* etc. In this connection one should, if possible, see the reproduction in the American Museum of Natural History of the animals of the wharf piles (Vineyard Haven Wharf Pile Group), showing the numerous sponges, hydroids, sea anemones, ascidians or sea squirts, shellfish and other sedentary animals with which the piles are crowded below the low-water mark (figure 19). A description of this group is given by R. W. Miner in the American Museum Journal for February 1913. Hundreds of Pink Hydroids are shown clustered in feathery colonies, the White-armed Sea Anemone and Brown Sea Anemone are scattered here and there, interspersed with coral red masses of the Red-beard Sponge. The ascidians or Sea Squirts are everywhere on the piles singly and in colonies. The common Edible Mussels are clustered thickly upon the piles and masses of coiled calcareous worm tubes also incrust them. Various fishes, the Blunt-tailed Squid and jellyfishes swim about. To those forms shown in this reproduction may be added the ubiquitous Acorn Barnacle, various small crustaceans and worms, the Green Starfish, quite a large number of snails such as the Oyster Drill, the Mud Flat Snail, two species of Littorina (the Rough Winkle and the Seaweed Snail) several bivalves such as the Common American Oyster, the Jingle Shells, the Ribbed Mussel as well as the Edible Mussel, the Ship Worm etc. and species of nudibranchs or Sea Slugs. Some of these forms are attached to the piles, others to the seaweeds growing upon the piles.

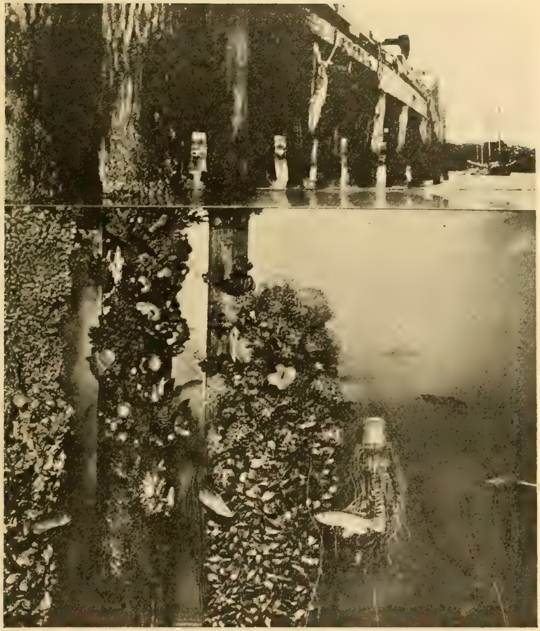


Figure 19 The Wharf-Pile group in the American Museum of Natural History. Designed and supervised by Doctor R. W. Miner. (Courtesy Amer. Mus. Nat. Hist.)

There is an association which might be termed the association of *floating* and *swimming forms.* These creatures are often cast upon the various shores and most of them have been discussed more or less under other associations. They include the medusa hydroids; the comb-jellies; the jellyfishes large and small; the free swimming hydrozoan colonies (siphonophores) such as the Portuguese Man-of-War (*Physalia*), a form of the tropical Atlantic and Gulf Stream sometimes seen floating along our coast late in summer; various worms in abundance; the Goose Barnacle (*Lepas fascicularis*) carried by the Gulf Stream and cast up on our shores late in summer; the Gulf-Weed Crab (*Portunus sayi*) which lives in masses of *Sargassum* or Gulf-weed and sometimes drifts from the tropical Atlantic to our coast in the summer; the Floating Snail (*Janthina fragilis*) which floats in the Gulf Stream off the coasts of Florida and the West Indies and is cast up on our shores by southerly winds; several species of scallops; species of squids or Sea Arrows; and the Paper Nautilus (*Argonauta*) which is found in the tropical parts of the Atlantic and Pacific oceans and occasionally drifts northward upon the Gulf Stream and is cast upon the south Long Island coast. There are two species of squids common to our coasts. The Blunt-tailed Squid (*Loligo peali*) is common from Cape Cod to South Carolina and frequents shallow water; the Short-tailed Squid (*Ommastrephes illecebrosus*) is the common squid of the New England coast ranging from Cape Cod to Newfoundland and used as bait in the Banks fishing. The Giant Squid (*Architeuthis princeps*), the largest living invertebrate, is seen rarely and then always off the Grand Banks or off the coast of New-

foundland. It attains a length of at least nine and one-half feet and only 30 specimens have ever been found.

Gravelly or *pebbly bottoms* have a characteristic fauna, and *shelly bottoms* support much the same life. There may be burrowing or tube-dwelling species, as many worms, small crustaceans, bivalve shells etc.; hydroids, bryozoans, bivalves, and numerous ascidians or sea squirts adhere to shells or pebbles; then there are species that hide among shells and pebbles such as crabs and other crustaceans; small crustaceans, some worms, snails, and most of the delicate bryozoans and hydroids live attached to hydroids, bryozoans, algae etc. living on shells and pebbles; also there are larger forms that creep and swim, such as the lobster, larger crabs, hermit crabs, large gastropods, mollusks, starfishes, sea urchins, sea cucumbers etc. Such bottoms are the feeding grounds of many kinds of fishes because of the abundance of food to be found there. Among the crustaceans may be listed the Common or American Lobster, Hermit Crab, Rock Crab, Common Shrimp, Spider Crab etc. Gastropods are represented by both species of Giant Whelks, Sand Collar Snails, Boat Shells, the wormlike *Vermetus*. The Edible Mussel, Horse or Bearded Mussel, the Common Scallop, the Bloody Clam, Cod Clam, Surf Clam and Jingle Shells are some of the bivalves. Bryozoans are very abundant, hydrozoans are numerous; there are few sea anemones and they are the same as on rocky bottoms; the Sulphur Sponge and the Star Coral are present. The Green Starfish, Green and Purple Sea Urchin, the Red and Crimson Sea Cucumber and the Common Brittle Star (*Amphipholis*) represent the echinoderms. A very delicate gray or whitish brittle star (*Amphiura squamata*) is found on shelly bottoms.

On and *under stones* in various situations occur sponges, as the Sulphur Sponge, hydroids, bryozoans, numerous worms of many kinds, anemones, the Star Coral and Dead-Men's Fingers, the Red and Crimson Sea Cucumbers, Sea Squirts, snails such as the Boat Shells, bivalves such as Mussels, the Bloody Clam and Jingle Shells etc. *Incrusting shells* are the same or similar forms, such as the Red Sponge, the Boring Sponge, the Star Coral and Dead-Men's Fingers, worms such as the Shell Worm (*Serpula*), bryozoans such as the Lace Coralline and False Coral, the Chiton on dead oyster shells, Boat Shells and Cup and Saucer Limpets (*Crucibulum*) among the snails, Jingle Shells and Mussels among the bivalves.

Salt marshes have their peculiar life. Fiddler Crabs are characteristic especially *Uca pugnax* which ranges from Provincetown, Mass., to Georgia and is so abundant that banks are completely honeycombed and undermined by it. Then there are the Salt Marsh Snails (*Melanpus bidendatus*). This species is most abundant upon the stems of the salt marsh grass near high-tide mark from Florida to Cape Cod and is common along the coasts of Long Island and New Jersey. The shell is brown in color and about the size and shape of a coffee berry. The snail itself is a vegetable feeder, but is preyed upon by crabs, sea birds etc. In the life of the salt marshes must be included the life of the eel-grass in brackish waters already touched upon in the discussion of muddy bottoms. Crustaceans, worms, snails and bivalves occur, some of the species the same as on muddy bottoms elsewhere, but not in the same numbers or as great varieties. There are several species of crabs that burrow along banks of streams and ditches in the salt marshes and of these the

Marsh Fiddler discussed above is the most abundant. Mud Crabs have been found in salt marshes, and Beach Fleas under drift and vegetable débris. Another small snail (*Littorinella minuta*), characteristic of the mud flats, is found in pools and ditches of salt marshes in numbers. Small fishes and various aquatic birds feed largely upon it. The Ribbed Mussel lives over salt marshes along borders of ditches and streams wherever there is sufficient moisture, with the shell partially imbedded in the mud or among the roots of the grass and anchored by a stout byssus.

There are various other associations. *Coral reefs* have their own life. The madrepore or stone corals are the reef-builders and with them are associated the hydrocorallines such as the Elk Horn Coral. Here occur also the Sea Fans, Sea Whips and Sea Feathers. Characteristic mollusks, worms, crabs, starfishes, sea urchins etc. are to be found here. It has been aptly stated that coral reefs are as thickly inhabited by other forms of life as the forests by birds and insects.

Parasites and *commensals* constitute another type of association. Two forms are rather interesting and may be met with. One of the sea anemones, the Parasitic Anemone (*Edwardsia leidyi*) lives in one of the jellyfishes, the Rainbow Jelly. It is a long, dull-pink, thread-like form looking like a worm. The female of the Oyster Crab (*Pinnotheres ostreum*) lives when mature in the gill cavity of the oyster. It is highly esteemed as a delicacy and sold at a high price. The female shell is pinkish white in color and thin, while the male is brown with light-colored central stripes and four white spots and has a hard shell. The male swims freely and has strong claws and legs, but the legs of the female are so weak

that it can not swim away from the oyster. It is unnecessary to touch further upon these associations. Those that have been given are quite suggestive.

Distribution of the Mollusks

From the above discussion of the animal associations along our coasts the reader should gain some idea of the geographical distribution of the representatives of the various groups. The mollusks along our shores and the mollusks, together with brachiopods, among fossils will probably attract most the attention of the beginner. It therefore would seem worth while to give a short survey of their distribution and the conditions that influence it. As we have seen, nearly every conceivable type of sea bottom or coast line between tides has its own peculiar type of molluscan life. There are borers in the rocks and borers in the shells of other forms. Some groups prefer to live on rocks above low-tide mark and here we find such forms as the Periwinkles, the Rock Snails, the Trochids, and the majority of the forms with patelliform (limpetlike) shells. Forms like the English Whelks, Stimpson's Sipho, and the Ten Ribbed Snail have a fondness for rocky or gravelly ground below low-tide mark; other mollusks prefer sandy bottoms; still others burrow in the mud. There are hosts of species that seek their homes in the tangled masses of seaweed or other vegetation etc.

It has been found that the temperature of the water rather than its depth appears to influence the distribution of marine life. In the discussion of mollusks of the different associations it has been pointed out here and there that certain cold water or arctic species that live in the shallow waters of the more northern coasts are found in

the deeper waters off the more southern shores of the United States. In general the arctic seas have their own characteristic fauna; and so also are there genera and species peculiar to the more temperate waters of Europe and America and to the warm waters of the tropical seas.

Along the Atlantic Coast of North America four provinces are recognized for the littoral and shallow-water species of mollusks — the Arctic, the Boreal, the Transatlantic and the Caribbean Provinces. Very cold-water forms of the circumpolar region, the *Arctic Province,* are found as far south as Newfoundland. Some of the characteristic genera of the arctic fauna are found along the coast of Maine and Massachusetts, as far south as Cape Cod, urged southward under the influence of the cold Labrador current. Among these genera are the bivalves *Mya, Leda, Yoldia, Astarte* and the snails *Buccinum, Chrysodomus, Sipho, Trophon, Bela, Velutina, Lacuna* and *Margarita* etc. The *Boreal Provinces* of Europe and North America correspond and as we have seen in our previous discussions they possess many forms in common. This province along American shores extends from the Gulf of St Lawrence along the New England coast to Cape Cod and is characterized by such bivalve genera as *Mytilus, Modiola, Nucula;* such genera of snails as *Purpura, Littorina, Lunatia, Neverita, Acmaea,* and *Margarita;* the Chiton, and the nudibranchs *Eolis* and *Doris.* The *Transatlantic Province* extends from Cape Cod to Florida. Some forms of the boreal province pass Cape Cod and live as far south as Long Island sound and certain genera of the transatlantic province live north of Cape Cod in Massachusetts bay though they do not thrive so well in the colder waters there. Cape Hatteras acts as a barrier forming a subdivision in

this province. South of the Cape the Antillean fauna begins to come in. The long stretches of sandy beach from Long Island to Cape Hatteras are not conducive to the development of a rich or varied fauna. Along the New Jersey beaches one finds the bivalves *Mactra, Arca* and *Ensis* and in more sheltered places the snails *Fulgur* and *Lunatia* which are the most characteristic forms of the northern subdivision of this province. The Gulf Stream approaches very close to the land near Hatteras bringing warm waters and a consequent sharp change in the appearance and abundance of the molluscan fauna. There is a suggestion of the West Indies here. Shells of *Cardium, Arca, Cancellaria, Dolium, Cassis* (Helmet Shells) are found on the beaches. As one approaches Florida and long stretches of exposed sandy beaches with shifting sands, the variety and richness of the molluscan life is again limited. The *Caribbean Province* extends from Florida to the northern shores of South America and includes the Bahamas, West Indies and Gulf of Mexico. The Caribbean or Antillean fauna is a warm-water fauna, rich and varied. Some of the conspicuous forms found on the Florida coast are the snail genera *Strombus, Oliva, Fasciolaria, Natica, Sigaretus, Littorina, Neritina, Melogena,* and the bivalve genera *Cardium, Tellina, Lucina, Cyrene* and *Callista.*

On the west coast four provinces are recognized for the mollusks of shallow and littoral waters — the Arctic, the Aleutian, the Californian and the Panamic Provinces. The *Arctic Province* includes the Bering sea and as we have already seen many of the forms characteristic of Labrador and Greenland appear here. The *Aleutian Province* extends down to Vancouver from the southern peninsula of Alaska. While some of the arctic forms

extend into this region it shows a gradually increasing number of west coast species and also species characteristic of the eastern boreal region which have passed through the cold waters north of America into the Pacific waters by way of the Bering sea. The *Californian Province* reaches from Vancouver to Cape St Lucas. In this province one notes a large development of patelliform (limpetlike) mollusks, *Haliotis* (the Abalone) and the chitons. The *Panamic Province* which includes the Gulf of California extends to South America and in its warm waters has developed one of the richest and most interesting of the faunas of the world.

LITERATURE

The references given here will be only such as are within the scope of the beginner. Some of them have full lists of references, so that any student can pursue his studies further if he wishes. The two books particularly recommended for the discussions of the rocks are Lahee ('23) and Pirsson ('10; '26 rev. by A. Knoff). To these references may be added any good textbook of geology such as Chamberlain and Salisbury ('09, ch. II); Cleland ('16, ch. VI–X; rev. '30); Grabau ('20, ch. V, VI, XI, XII, XVI–XX); Pirsson ('20, ch. XI–XIV); Pirsson and Schuchert ('15, ch. XI–XIV); Scott ('24, pt II). Grabau ('13) is a more advanced and more technical piece of work but here will be found numerous full bibliographies.

Many sources have been drawn upon for the chapters on conditions of life in the sea today, but the following references, some of which carry additional bibliographies, will suffice for the beginner. First should be mentioned Flatterly and Walton ('22) and Verrill ('73). Other

books that may be read are Arnold ('03), Crowder ('28), Johnstone ('08), Lull ('17, ch. V), Mayer ('11). Grabau ('13), while of a more technical nature has certain chapters (III–V, XV, XXVI, XXIX), parts of which will be found very interesting, especially chapters XXVI and XXIX. A number of the many papers on the subject are cited here and will be found both interesting and suggestive. These are Allee ('23), Allen ('21, '27), Brandt ('01), Clark ('25), Dall ('90), Davenport ('03), Haeckel ('93), King and Russell ('09), Michael and Allen ('21), Miner ('13), Murray ('98), Packard ('18), Pearse ('13), Peterson ('18), Pilsbry ('91), Ritter ('09), Shelford and Towler ('25), and Sumner ('08). Many of these papers contain lists of literature, as indicated in the bibliography. Goldring ('22) gives a summary of the effects of decreased salinity on the fauna of the Baltic sea today and the Pleistocene fauna of the Champlain valley. Any good textbook of zoology will be found useful.

THE FORMATIONS

Sediments in the geologic past were deposited under much the same conditions as those today and have become the conglomerates, sandstones, shales, limestones etc. constituting our geological formations. Animals and plants in the past also were influenced by their environment much as today, forming plant and animal associations then as now and giving us the characteristic faunas and floras of our formations. Certain types of fossils are characteristic of sandstones; others of limestones, shales etc., varying as the conditions under which they lived varied at the time of deposition of the sediments making the rock.

The conditions for the preservation of fossils in the rocks and their significance is discussed in part 1; the time scale and rock scale and the stratigraphic sequence of sedimentary rocks in the introduction to this volume pages 60, 61). Briefly, the normal sequence of undisturbed rock from older to younger, that is, from earliest deposited to latest deposited, is termed the *stratigraphic sequence.* In the division of the time and rock scales, the *era* of time corresponds to a *group* of rocks. Eras are the longest divisions of time used in geology and they are separated by great unconformities and marked near their close by times of extensive mountain building, bringing about great changes in the environment with a consequent striking effect upon the life of the times. Eras are composed of *periods* of times with their corresponding *systems* of rocks. Periods of time are of very long duration and systems of rocks are usually of great thickness. They

are separated primarily by marked differences in the fossils contained in the rocks, but also by crustal disturbances. Periods are composed of *epochs* of time and systems of formations of *series* of strata. These divisions are still more or less arbitrary, and are based either upon the fossil content of the series of strata or the sedimentary cycle which the strata are assumed to represent. The further division of epochs into *ages* and series into *stages* follows, but these divisions are not as yet as definitely delimited.

The *formation* is the unit of chronological or time classification of rocks and in general use is the smallest unit that can be plotted on a geological map. A formation may be either igneous or sedimentary. If sedimentary it may be a single thick bed of rock, such as the Onondaga limestone, a succession of like beds or a succession of sediments that are unlike but have closely related faunas, such as the Hamilton beds. Where there is more than one member the beds are conformable, that is, showing no significant time breaks, and were deposited during a limited time in the earth's history. Formations bear local names based upon the town, river etc. with which the formation is associated. Their horizontal extent is limited since the conditions under which they were deposited were of local character and varied from place to place. Two formations may be laid down at the same time in different places and be of a different lithological character, that is, one may be a sandstone and another a limestone. Sometimes, when first studied, the age relationship is not recognized and the formations receive different names though of the same age. If their identity in age is recognized from the beginning they receive the

same name though lithologically different. Sometimes further study, particularly of the fauna, shows that a thick succession of like sediments, such as shales or limestone beds, which have always been regarded as a single lithological unit, is made up of several distinct members to which formation names are given. The old name may be discarded or used to designate a part of the previous compound formation.

William Smith (1769–1839), known as "Strata" Smith and the "Father of English Geology and Stratigraphy" was the first to recognize the value of fossils in determining the age of formations, (1799–1801). English geologists have played a leading part in the detailed subdivision of the rocks of the earth's crust and therefore we find that many of the terms that have in general a world-wide acceptance were proposed by them. Much has been done since then in countries all over the world. Divisions have been more exactly delimited and with closer study finer and finer subdivisions have been made. Fossils now are regarded as the primary basis for determining the sequence of geological formations, and when they are not present age is determined by a study of the lithological character and other considerations. There are many things that make the correlation of formations difficult. Folding and faulting may have disturbed the normal sequence or again through erosion isolated patches, separated by great distances, may be all that remains of a bed of rock. The lithological character of a rock, also, may change from one place to another, or formations may be separated by an unconformity, the missing beds being present in another locality. By study-

ing a series of formations in a number of different localities and by piecing these sections together, a complete record of this portion of geological time may be obtained as the sections studied are likely to supplement one another.

Geological formations are recorded on a *geological map,* which has a topographic map as a base. The more common type of geological map is the one in which the formations are drawn continuously even over regions where there are no outcrops. Contacts not seen may be indicated by a dotted line. Structures such as faults etc. are shown, and fossil localities may also be indicated. The other type of geological map shows only the outcrops with dips and strikes indicated and also other structures as faults etc. A geological map may show only the rock structures, or account may be taken of the surface conditions. The former is the more easily read map, but is to a certain degree misleading to a field explorer, since actual outcrops are not shown; in the latter, an overprint or over-coloring indicates the surface material and leaves the actual outcrop areas untouched. In the former type of map actual outcrop areas may be indicated by deeper coloring. Whichever the type of map used it embodies the geology of the area as interpreted by the geologist from the outcrop map made in the field. Geological maps showing only outcrops of the several geological systems (Cambrian, Ozarkian, Canadian, Ordovician, Silurian etc.) are known as *system maps;* those showing the formations, such as the folio maps published by the United States Geological Survey and the large scale map sheets published by the New York

State Survey are known as *formation maps.* A key to the color scheme accompanies a geological map. This is known as the legend and consists of small rectangles colored to correspond to the colors on the map and usually arranged in an ascending series from the oldest to the youngest rocks. Often some pattern is used with the color and perhaps in addition some form of notation as the numbers used to denote each system on the geological map of North America and the letters used to denote formations, as *Do* for the Onondaga formation of the Devonian, and *Sm* for Silurian Manlius etc. In figure 20 is seen a geological map of New York State showing the surface expression of the various systems of rocks, and accompanying cross-sections are shown in figures 21, 30, 44. *Geological sections* accompanying geological maps show the true relationships of the various systems or formations. They may be natural cross-sections, columnar sections or restored sections. The *cross-section* shows the profile of the country and the position and structure of the rocks beneath as they are at the present time. They may be drawn with the same vertical and horizontal scale or the vertical scale may be exaggerated, sometimes five and ten times as much as the horizontal scale, where the section made is of great horizontal extent. A columnar section shows the vertical succession of rocks. If one imagines a shaft sunk through a series of horizontal strata the sides of the shaft would constitute a columnar section of the rocks cut through. These sections when drawn to scale are important records. Such sections from different regions show variation in the character and thickness of the rock

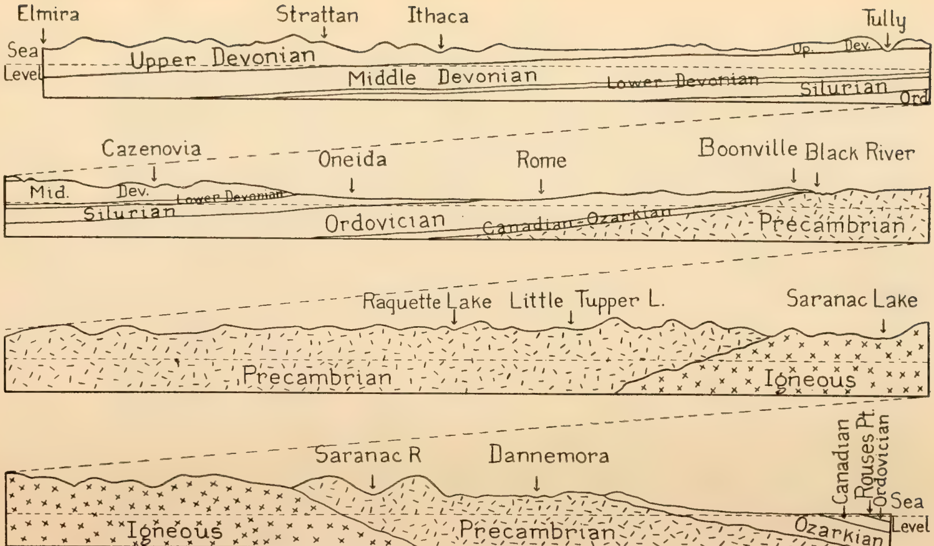


Figure 21 Northeast-southwest section across New York State. From Elmira across the Upper Mohawk valley and the Adirondacks to Rouses Point. Horizontal scale: approx. ½ inch = 6 miles. Vertical scale: approx. ½ inch = 5280 feet.

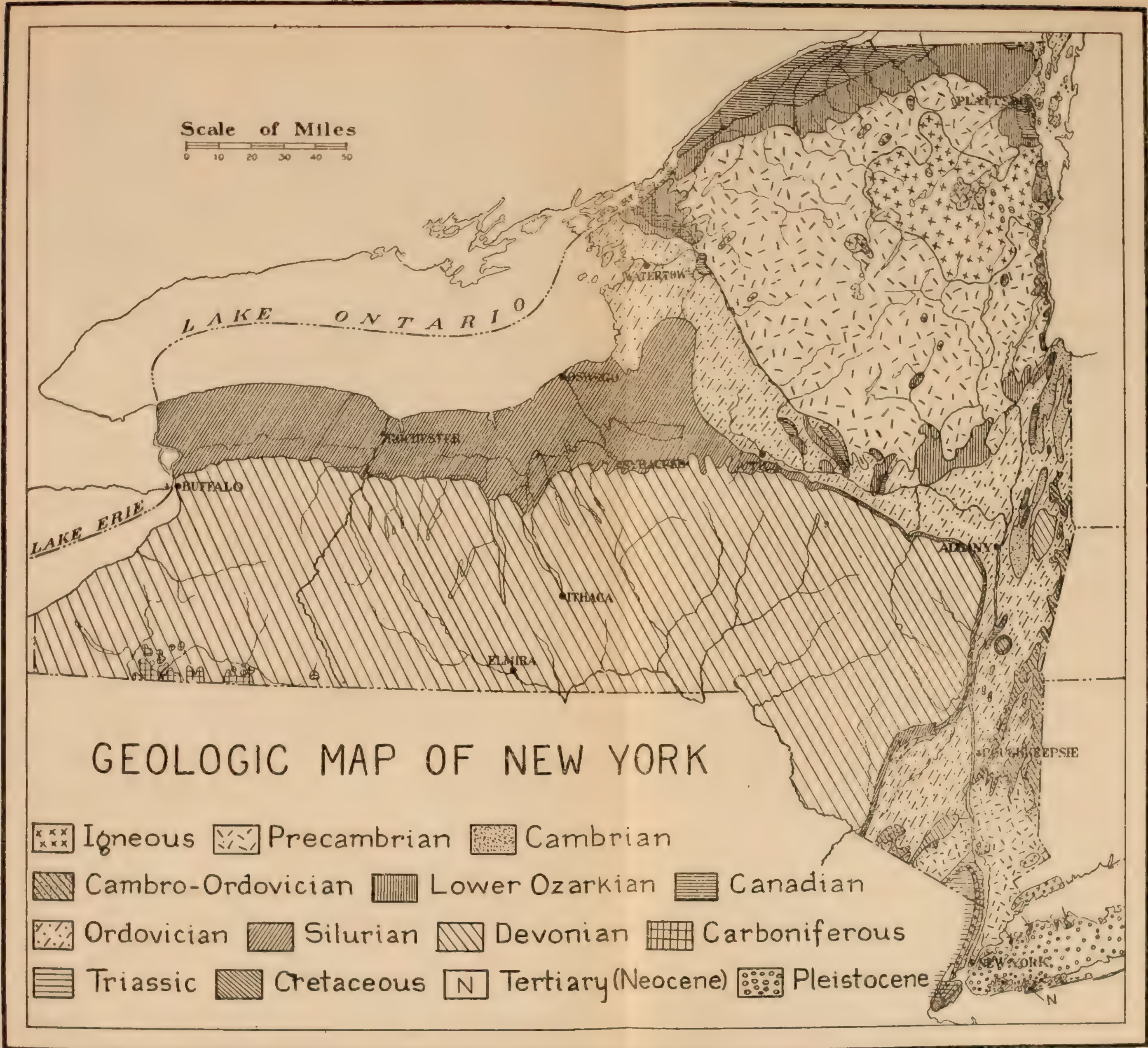


Figure 20 Geologic map of New York State. In the Adirondack area the Precambrian as shown is unclassified, except the central anorthosite (igneous) mass.

from place to place. From columnar sections *restored sections* are made, that is, sections aiming to show the conditions as they existed during the period of formation of the strata. Columnar sections are local geological columns and by matching together such vertical sections a *geologic column* for the world has been built up showing the succession from the oldest to the youngest beds. A geologic column showing the most important formations of New York State will be found below (table 2). *Type sections* for a formation or formations are constituted by the regions in which the geological formations of a series or system were first studied and the succession worked out.

It is not intended here to give a detailed discussion of all the separate formations found in New York State. It is beyond the scope of a handbook of this nature. Table 1 gives the most important formations grouped as to periods and series and table 2 presents geologic columns of the most important formations in western, west central, central, east central and eastern New York. Both tables are based upon the Classification of the Geologic Formations of the State of New York (Hartnagel '12). For a detailed table of the formations the student is referred to this work. (See figures 20, 21.)

TABLE I

Geologic time scale for New York State

Era or Group	Major Divisions	Period or System		Epoch or Series	Age or Stage
Cenozoic	Late Cenozoic	Pleistocene or Glacial			
Mesozoic	Late Mesozoic	Upper Cretaceous		Upper Cretaceous beds	Representatives of parts of Monmouth, Matawan and Magothy formations
		Lower Cretaceous		Upper Potomac series	Raritan and Cliffwood formations
	Early Mesozoic	Upper Triassic		Newark series	
Paleozoic	Late Paleozoic	Pennsylvanian (*Upper Carboniferous*)		Pottsvillian	Sharon shale
					Olean conglomerate
	Middle Paleozoic	Mississippian (*Lower Carboniferous*)		Bradfordian	Knapp beds
					Oswayo beds
					Cattaraugus beds (incl. Kilbuck, Salamanca, Panama and Wolf Creek conglomerates)
		Devonian	Upper	Chautauquan	Chemung beds (Catskill sandstone, local facies)
				Senecan	Portage beds (Naples beds, Ithaca beds, Oneonta beds — local facies)
					Genesee beds
					Tully limestone
			Middle	Erian	Hamilton beds (incl. Marcellus shale)
				Ulsterian	Onondaga limestone
					Schoharie grit
			Lower	Oriskanian	Esopus grit
					Oriskany sandstone
				Helderbergian	Port Ewen limestone
					Alsen limestone
					Becraft limestone
					New Scotland limestone
					Kalkberg limestone
					Coeymans limestone (Upper Manlius or Keyser)

Table I — *Continued*

Geologic time scale for New York State

Era or Group	Major Divisions	Period or System		Epoch or Series	Age or Stage
Paleozoic	Early Paleozoic	Silurian or Ontarian	Upper	Cayugan	Manlius limestone
					Rondout waterlime
					Cobleskill limestone
					Salina beds
			Middle	Niagaran	Lockport dolomite (incl. Guelph dolomite)
					Clinton beds (incl. Rochester shale at top; Oneida conglomerate at base)
			Lower	Medinan	Upper Medina beds
					Queenston shale
		Ordovician or Champlainian	Upper	Cincinnatian	Oswego sandstone
					Pulaski shale
					Frankfort shale
					Utica shale
			Middle	Mohawkian	Trenton beds
					Black River beds (incl Lowville limestone)
			Lower	Chazyan	Chazy limestones (Normanskill shale of Chazy age)
		Canadian (*Ulrich 1911*)	Middle & Upper	(*Canadian series of authors; with Chazyan = Lower Ordovician*)	Beekmantown limestones (Deepkill shale of same age)
			Lower		Tribes Hill limestone (Schaghticoke shale in east)
		Ozarkian (*Ulrich 1911*)	Lower	Ozarkian (Saratogan) = *Uppermost Cambrian of authors*	Little Falls dolomite
					Hoyt limestone
					Theresa sandstone
					Potsdam sandstone
		Cambrian or Taconian	Middle	Acadian	Stissing limestone
			Lower	Taconian (Georgian)	Georgia beds
					Poughquag quartzite
Precambrian		Grenville series			

TABLE 2

Geologic columns for New York State

Showing extent of most important Paleozoic formations along their strike from west to east

System		Western	West Central	Central	East Central	Eastern
Pennsylvanian (Lower)		Sharon sh.	*	*	*	*
		Olean cgl.				
Mississippian (Lower)		Knapp beds	*	*	*	*
		Oswayo beds				
		Cattaraugus beds				
Devonian	Upper	Chemung beds	→	→	→	Catskill beds
		Portage beds (Naples fauna)	→	(Naples-Ithaca fauna) → ←	←	Portage beds (Ithaca fauna)
		Genesee beds	→	→	*	*
		Tully horizon	→	→	→	
	Middle	Hamilton beds				Hamilton beds
		Moscow sh.	→	→	←	
		Ludlowville sh.	→	→		
		Skaneateles sh.	→	→	→	
		Marcellus black sh.	→	→	→	Marcellus black sh.
		Onondaga l. s.	→	→	→	Onondaga l.s.
		*	*	*	←	Schoharie grit
					←	Esopus grit
	Lower	*	*	Oriskany s.s.	→	Glenerie l.s.
		*	*	*	*	Port Ewen l.s.
					←	Alsen l.s.
					←	Becraft l.s.
					←	New Scotland l.s.
					←	Kalkberg l.s.
				←	←	Coeymans limestone (Upper Manlius or Keyser)

Note: — An asterisk (*) indicates that the unit is absent from outcrops in the region represented by the column in which it stands. The arrows (→) indicate the continuation of the units east or west. *Sh.*, shale; *ss.*, sandstone; *cgl.*, conglomerate; *l.s.*, limestone; *w.l.*, waterlime; *dol.*, dolomite; *qtze.*, quartzite.

TABLE 2 — *Continued*

Geologic columns for New York State

Showing extent of most important Paleozoic formations along their strike from west to east

System		Western	West Central	Central	East Central	Eastern
Silurian	Upper	*	←	←	←	Manlius l.s.
			←	←	←	Rondout w.l.
		Akron dol. (= Cobleskill)	→	→	←	Cobleskill l.s.
		Salina beds				Salina beds
		Bertie w.l.	→	→	→	Rosendale w.l.
		Pittsford sh.	→	→	→	High Falls sh.
	Middle	Lockport dol.	→	→	→	*
		Guelph dol.	→	*	*	
		Clinton beds				
		Rochester sh. (top)	→	→	→	Shawangunk cgl.
		Thorold s.s. (base)	→	Oneida cgl.	→	
	Lower	Upper Medina beds	*	*	*	*
		Queenston sh.	→			
Ordovician	Upper	[*Ordovician restricted of Ulrich*]		Oswego s.s.	*	*
				Pulaski sh.	*	*
				Frankfort sh.	→	Indian Ladder beds
				Utica sh.	→	*
	Middle	*	*			Trenton beds
				*	←	Schenectady sh.
				Trenton l.s.	←	Canajoharie sh. (Snake Hill sh. of same age in east.)
				*	←	Glens Falls l.s.
		[*Ordovician restricted of Ulrich*]				Black River beds
				*	←	Amsterdam l.s.
				←	←	Lowville l.s.
	Lower			Chazy age (Pamelia l.s.)	*	Chazy beds (Normanskill sh. of Chazy age)

Note: — An asterisk (*) indicates that the unit is absent from outcrops in the region represented by the column in which it stands. The arrows (——→) indicate the continuation of the units east or west. *Sh.*, shale; *ss.*, sandstone; *cgl.*, conglomerate; *l.s.*, limestone; *w.l.*, waterlime; *dol.*, dolomite; *qtze.*, quartzite.

TABLE 2 — *Continued*

Geologic columns for New York State

Showing extent of most important Paleozoic formations along their strike from west to east

System		Western	West Central	Central	East Central	Eastern
Canadian (*Ulrich 1911*)	Middle & Upper	[*Canadian series of authors; with Chazyan = Lower Ordovician*] *	*	Ogdensburg dol.	←	Beekmantown l.s. (Deepkill sh. of same age)
	Lower			←	←	Tribes Hill l.s.
				*	*	Schaghticoke sh.
Ozarkian (*Ulrich 1911*)	Lower	[= *Uppermost Cambrian of authors*]	*	*	←	Little Falls dol.
				*	*	Hoyt l.s.
				←	←	Theresa dol.
				←	←	Potsdam s.s.
Cambrian	Middle	*	*	*	*	Stissing l.s.
	Lower			*	*	Georgia beds
				*	*	Poughquag qtze.

Note: — An asterisk (*) indicates that the unit is absent from outcrops in the region represented by the column in which it stands. The arrows (→) indicate the continuation of the units east or west. *Sh.*, shale; *ss.*, sandstone; *cgl.*, conglomerate; *l.s.*, limestone; *w.l.*, waterlime; *dol.*, dolomite; *qtze.*, quartzite.

PRECAMBRIAN ERAS

The basal rocks of the Paleozoic era are separated from the rocks below by a pronounced unconformity. The underlying rocks show a smooth, well-eroded surface which sometimes approaches a perfect plane; and, since these rocks are highly folded and metamorphosed and the Paleozoic beds above do not show such a degree of distortion and metamorphism, it is evident that the older rocks suffered extreme metamorphism and then were subjected to a long period of erosion before the deposition of the Paleozoic sediments. Typical sections show that the usual relationship of the Paleozoic and pre-Paleozoic rocks is that of a bed of quartz-sandstone resting upon the crystallines. The age of this basal sandstone has been found to be Lower, Middle or Upper Cambrian etc., even Ordovician in some sections, indicating overlapping formations deposited by a transgressing, but not continuously transgressing, sea. The basal quartz-sandstone followed by limestones rather than by clay shales indicates that the surface of the land had been worn down to the extent now seen and the products of disintegration had been well worked over and sorted by wind and water before the advance of the Cambrian sea over much of North America.

Studies of the Precambrian rocks were first made by Sir William Logan, the first director of the Canadian Geological Survey, who is known because of this as the Father of Precambrian Geology. An absence of fossils makes the correlation of Precambrian rocks very difficult, particularly where they are in distant or isolated places. Even the lithological character

varies greatly in a short distance. The criteria used for determining geologic sequence in these rocks must be of a physical nature, such as the lithological character of the rock, superposition of the formations, crustal movements and cycles of erosion. Geologists in general admit the extreme length of geologic time and more than half of geologic time has been allotted to the Precambrian eras. Some even believe that the Archeozoic alone may have been longer than all the subsequent eras taken together. The thought is suggested that the appearance of the Cambrian fauna, though many millions of years ago, might be regarded as a comparatively recent event if the degree of life development is taken as a basis by which to measure time.

These older crystalline rocks so sharply set off from the younger Paleozoic beds have been grouped together into two Precambrian eras, the Archeozoic and Proterozoic. Some authors use for the Archeozoic the term Archean (ancient) which once covered all the Precambrian formations. The Proterozoic era includes the Algonkian of authors. Precambrian rocks (Archeozoic and Proterozoic), according to estimations, appear at the surface over one-fifth of the land area; but, while this means it is not covered by younger rocks; it may be covered with soil or glacial deposits.

Archeozoic and Proterozoic

Geology. The Archeozoic era comprises rocks that are greatly altered and has been termed the *Age of Larval Life;* the Proterozoic era comprises rocks that are not much altered and is known as the *Great Iron Age* and

also the *Age of Primitive Invertebrates.* The two eras are separated by a widespread unconformity and are classified as follows:

Ep-Proterozoic Interval and Peneplanation of Continents

	Late Proterozoic (Keweenawan series)	
	(*Break in Record*)	
Proterozoic	Middle Proterozoic	Animikian series
(*Former Life*)	*Unconformity*	Huronian series
	Lower Proterozoic (Sudburian series)	

Ep-Archeozoic Interval and Peneplanation of Continents

	Laurentian granites
Archeozoic	? Grenville series (May prove to be
(*Ancient Life*)	Proterozoic (Huronian)
	Keewatin — Coutchiching series

Beginning of earth history

Geologists have not as yet seen the original foundation upon which the Archeozoic rocks rest nor have they any evidence as to what took place in earliest Archeozoic time. It is thought that the surface of the earth in earliest geologic times must have been made up of igneous rocks, probably mostly granites. With the appearance of rains erosion of the rocks began and the first sediments were deposited — sandstones and mudstones. The first limestones were probably chemical but later were deposited through the agency of organisms. No rocks are more complex than those of the Archeozoic era. They are known as the basement complex: first, because they are the oldest rocks of which we have any present knowledge and, as far as known, underlie all the younger rocks of the earth's crust; second, because of their highly altered, complex, present nature. None of the formations are in their original condition. They have been uncovered in regions where there has been repeated uplift and erosion and these can be studied. The greatest ex-

tent of Archeozoic rocks is found in eastern Canada in an area of about 2,000,000 square miles that forms an irregular mass around Hudson bay and extends south into Wisconsin and Minnesota. This is known as the Canadian or Laurentian Shield in which some geologists have included Greenland and the Adirondacks of New York State. Crystalline rocks partly of Archeozoic age appear in New England and in a belt stretching from Maryland south to Alabama (the Piedmont Plateau area). Archeozoic rocks are also found in the western part of the continent forming the cores of the mountains and in isolated patches elsewhere. The Canadian Shield is chiefly formed of the widely distributed Laurentian gneisses and granites which represent numerous batholiths that welled up into the earlier sediments (Keewatin and Grenville series).

In the lowest Archeozoic series are the oldest sedimentaries known (Coutchiching formation), typically exposed in the Rainy Lake district of Canada north of Minnesota. They consist of graphitic mica-schists, derived by metamorphism from carbonaceous shales, and dolomites, both probably of marine origin and showing a thickness of 4600 feet. The Keewatin series, overlying the above, has a wide distribution and is best known in the Lake of the Woods area in the extreme western part of Ontario. This series has a thickness ranging from 6500 to 23,700 feet and consists of a succession of dark lava flows, ash beds and black carbonaceous and sandy mudstones. The lava flows are usually basalts metamorphosed to greenstones and green schists, and the mudstones have also been altered to schists. The upper 1500 feet of this series consists of interbedded banded jasper and iron ore and also contains limestones. The iron ore

has been altered to hematite and magnetite and is mined. The Grenville series also is of widespread distribution, but will be discussed separately below because of its occurrence in New York State. The Laurentian gneisses and granites have been touched upon. As they are intrusives they are younger than the Keewatin and Grenville series into which they have been thrust.

The Archeozoic was a time of unusual volcanic activity and great deformation. Batholiths of granite are of so frequent occurrence as to be almost characteristic of the era, and in certain regions a large part of the rock surface consists of them. They are broken, faulted and have been intruded by lavas of later age. Dikes cut across the schists and the Laurentian granites and gneisses. This oldest series of rocks consists then largely of lava flows and tuffs, with occasional beds of sedimentary rocks and beds of iron, broken by faults and massive intrusives, folded, contorted and so metamorphosed that former conditions are obscured. Valuable deposits of minerals — copper, iron, nickel, cobalt and silver — have promoted the study of these rocks, detailed knowledge of which is confined to the region around the Great Lakes and the St Lawrence river where excellent exposures have been revealed by glaciation. The Archeozoic era closed with a period of mountain building, the Laurentian Revolution, at which time occurred the intrusion of the Laurentian granites. This was followed by a long period of erosion resulting in peneplanation of the highlands, the Ep-Archeozoic Interval (*epi,* upon).

The Proterozoic era represents at least one-fourth of geologic time. It comprises in the Lake Superior region 53,000 feet of stratified rocks and 22,000 feet of volcanics; in the Rocky Mountains area about 37,000 feet.

Three divisions of time are recognized here, Early, Middle and Late Proterozoic. Proterozoic rocks on the whole are only slightly deformed, and therefore are sharply set off from the underlying strongly folded Archeozoic series with its many igneous intrusions by this condition of the strata as well as the widespread unconformity. They are also mainly sedimentary (volcanic rocks are subordinate) and when not too greatly metamorphosed are similar in all essential respects to the rocks of later eras. The Early Proterozoic rocks (Sudburian series) overlie the Laurentian peneplane from Lake Huron north to Sudbury, Ontario, and are not known elsewhere. They have a total known thickness of about 20,000 feet, consisting of white, cross-bedded quartzites with interbedded shales (15,000 feet) and below this cross-bedded arkoses and impure sandstones or graywackes (5000 feet) and sometimes a basal conglomerate. The upper deposits probably represent great alluvial or delta deposits; the lower are found in close association with the Laurentian granites and were formed through the disintegration of these either under desert conditions or, more probably, in a cool moist climate. These lowest Proterozoic beds are so little altered when not intruded by later igneous eruptions that original structures such as bedding, cross-bedding and ripple marks may be seen. They are much metamorphosed where intruded by the granites and are also deformed, thus being sharply set off from the Huronian series above, which are nearly flat or only gently folded. The Early Proterozoic is marked at the end by a period of mountain making followed by an erosion interval.

The Middle Proterozoic rocks rest unconformably upon the Lower Proterozoic and the unconformity is con-

sidered equal to that between the Archeozoic and Proterozoic systems. The Huronian series consists of a marine series and above this a marine and fresh-water series resting upon an erosion surface and having at its base a glacial boulder conglomerate or *tillite,* the oldest-known glacial deposit. The two series are composed of quartzites, conglomerates, limestones and graywackes, with a combined thickness of about 15,000 feet in the Lake Huron region. Above the Huronian series, with a break between, is the Animikian or Great Iron Series in which are found the largest and richest deposits of iron in North America. Seventy per cent of the hematite ores found in the Archeozoic and Proterozoic formations of the Lake Superior region occur in this series of rocks. These strata are still for the most part horizontal and from the widely isolated remnants are estimated to have a thickness of 6000 to 14,000 feet in places, the latter in the Penokee area of Michigan. They have a widespread distribution over the Canadian shield. The formation usually begins with a basal conglomerate followed by cherty limestones and dolomites, carbonaceous shales and beds of sandstone. No fossils have been found, but the general character and appearance of the beds points to a marine origin, though some seem to have a continental character.

The Late Proterozoic is separated from the Middle Proterozoic by a break in the record. The Keweenawan is a series of volcanic and continental formations with an estimated thickness of 50,000 feet of which 15,000 feet are sedimentary rocks. This system is characterized, in contrast to the lower Proterozoic series, by the presence of numerous lava beds, aggregating an enormous thickness, estimated at about six miles. Sixty-five distinct

lava flows and five conglomerate beds have been found in northwestern Minnesota and neighboring portions of Wisconsin. The igneous outbursts became less frequent toward the close of this period and sedimentary deposits increased. It is in the lavas and conglomerates of this time that the rich copper deposits of the Lake Superior region are found. The Keweenawan series are regarded by some geologists as belonging to the Cambrian.

The Proterozoic era closed with a period of mountain building which was followed by a prolonged interval of erosion and peneplanation of the continent. The unconformities separating the various divisions of the Proterozoic in the Lake Superior region are quite distinct and are marked by erosion surfaces and basal conglomerates, by differences in degree of metamorphism and amount of volcanic eruption. Another region where Proterozoic rocks have been identified is the Grand Canyon, Arizona, where nearly 12,000 feet, mostly sandstone, are exposed. They also form the cores of many of the western mountain ranges, the thickest sediments occurring in western Montana, eastern Idaho and British Columbia where the combined sections show a thickness of 37,000 feet, mainly sandstones and shales. Proterozoic rocks have been identified in the Black Hills of South Dakota and also in the Piedmont Plateau of eastern North America with some certainty.

Life. Direct evidence from fossils for the existence of life in the Archeozoic is very scanty. Sir William Dawson's Eozoön canadense (Canadian dawn animal) is no longer regarded as a fossil, but is believed to have its origin in the metamorphism of calcareous deposits formed through the agency of some organism, probably a marine alga. Indirectly life is indicated by the vast amount of

graphite found so widely spread in these ancient rocks. This graphite is largely derived by the metamorphism of carbon from organic bodies. It has been shown that the atmosphere and particularly the hydrosphere of the Archeozoic must have been of a nature capable of supporting life. In our oceans today numerous small crustaceans, countless jellyfishes and an abundance of microscopic life are found living near the surface where there is an abundance of food supply, and the chances for their preservation as fossils would be very small since hard parts are usually necessary for preservation. A primordial life might well be expected in the Archeozoic of the nature of the larval forms of today, soft-bodied creatures too perishable and minute to be preserved as fossils. The highly organized fossils of the Cambrian show a degree of specialization that indicates a long period of preceding life.

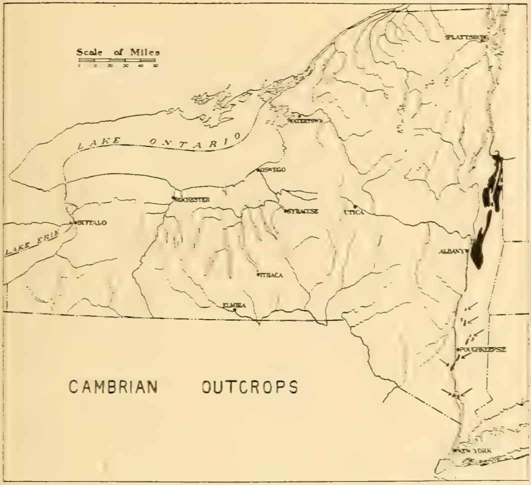
The Proterozoic rocks which were so long deemed nonfossiliferous have yielded a variety of forms in the past twenty-five or thirty years. *Silicious sponge spicules,* possibly *Foraminifera, worm tubes* and *trails, bacteria* and *algae.* The indications are that there was an abundance of marine algae of a calcareous nature in the seas of this time and thousands of feet of Proterozoic limestone were built up by them. Blue-green algae are also responsible for certain limestone beds. Just as in the Archeozoic, there must have been countless numbers of soft-bodied primitive forms not suited to preservation as fossils. The development of hard coverings came later probably as a protection and due largely to competition.

Climate. The presence of a glacial boulder conglomerate (tillite) in the Huronian series of Canada

indicates that this area suffered a period of glaciation at this time such as our Great Ice Age. Tillites of Proterozoic age, sometimes resting upon a striated rock pavement, have now been discovered on the north coast of Norway, in eastern China, India, South Australia and probably South Africa. Some investigators believe that some of these ice ages belong to the Cambrian and that the Cambrian began with a glacial climate but this has not yet been established. For long stretches of time the climate of the Precambrian must have been mild and fairly uniform over all the world, since the thick limestone deposits, the algae concretions and beds of iron all indicate mild conditions at the time of their deposition. The glacial periods appear to have been of short duration, geologically speaking, and to have taken place at times when the land stood highest.

The Grenville Series of New York

The Grenville series are a vast succession of sedimentary rocks, essentially calcareous, which due to metamorphism have become *crystalline limestones, gneisses, hornblende schists* (*amphibolite*) and *quartzites.* They are not only the oldest rocks in New York State but are among the oldest rocks of the earth. These beds are generally believed to belong to the Archeozoic era and constitute the thickest known series of Archeozoic strata, though more recently some geologists have come to the belief that they are of Proterozoic (Huronian) age. The Grenville series was first described by Logan and named after the township of Grenville. These strata occur in Ontario, in the region north of Lake Ontario and east of Lake Huron and it has been estimated that here there is a total thickness of 94,000 feet (18 miles) of which



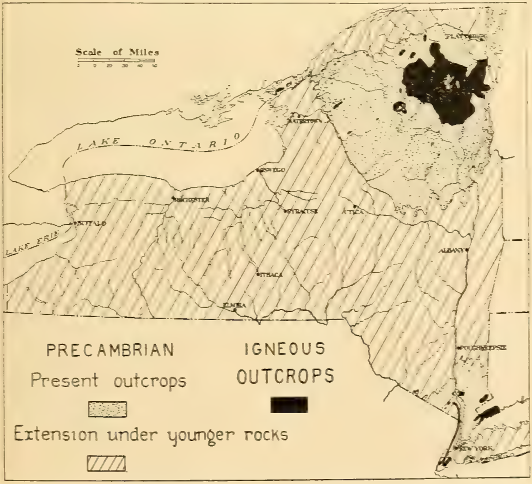


Figure 22 Precambrian and Cambrian (lower and middle) outcrops. In the Adirondack area the Precambrian as shown is unclassified, except the central anorthosite (igneous) mass. No Upper Cambrian (St Croixian) is present in New York State.

about 50,000 feet is limestone. This calcareous phase is restricted to southern Ontario, the Adirondacks in New York State and Quebec, but the Grenville series is also found in the Thousand Islands, probably in the Highlands-of-the-Hudson, southern Baffin Land and covering much of Labrador. In this series the crystalline limestones alternate with quartzites which are altered sandstones. There are also interbedded gneisses and schists formed partly from the intruded igneous rocks and partly from the sediments in contact with these intrusives. The Grenville strata have been so greatly changed that certain of the sedimentary characters have been obliterated, but among the proofs of their sedimentary origin is the common occurrence of the rocks in alternating layers, sharply contrasted in composition and color and indicating a difference in the original sediments. The extensive beds of crystalline limestone and beds of almost pure quartz rocks also indicate sedimentary origin, as well as the flakes of graphite, derived from carbon of organic origin (primitive marine plants) so common throughout the formation. Graphite is so abundant in the beds of Essex and Saratoga counties that it has been very extensively mined as a mineral.

The Adirondacks also are noted for their rich iron ores (magnetite and hematite) which have been extensively worked along the east and in the northwest and northern areas. Large bodies of magnetite in the central Adirondacks remain undeveloped. These deposits are somewhat remote from railroads but the resources of the district are probably the greatest in the Adirondack region.

The fact that the Grenville series is found in northern (Adirondacks) and southeastern (Highlands-of-the-Hudson) New York, along the western border of New England and in the Province of Ontario, north of Lake On-

tario, makes it more than likely that the Grenville series underlies the Paleozoic of western New York likewise (figure 22). In that case, during Grenville time a great expanse of ocean must have covered most, if not all of the state. The character of the sediments indicates deposition in a shallow transgressing sea and that the waters were warm. As the limestones disappear and give way to quartzites, gneisses and schists (original sands and mud) toward the Hudson Bay region, the indications are that the source of the material was in this region and that this part of the Canadian Shield must then have already existed as a continental area. After the deposition of the Grenville sediments there occurred a period of igneous activity on a large scale when great masses of molten rock were pushed into the sediments from below, breaking up the Grenville into patches. These rising batholiths domed up the strata above so that, due to the extensive erosion that followed the uplift of the great mass of Grenville sediments and associated rocks into the first known Adirondack Mountains, the sedimentary rocks are now found only in the deeper Grenville synclines between which are the igneous domes. Minor igneous activity toward the close of the Precambrian resulted in the formation of dikes which cut across these deep-seated igneous rocks, showing their younger age.

The *crystalline limestones* are the most striking formations of the Grenville series in the Adirondacks. They are more often colored and contain graphite, mica, hornblende and serpentine, but sometimes there is a coarse white marble. Serpentine is common in these marbles and the fossillike *Eozoön canadense.* The crystalline limestones are found most abundantly on the northwestern side of the Adirondacks where they occur in

parallel belts. There are other important areas in the east, in Essex county, and a number of scattered areas on the north and south sides and in the interior. The *sedimentary gneisses* have a distribution that corresponds in general to that of the limestones on the border of the Adirondacks where they are most widely distributed. They also occur in certain areas in Warren and Washington counties where the limestone is found only occasionally. The *amphibolites* or *hornblende schists* are in part at least derived from shales, though some probably originated from metamorphism of diabases or gabbros. They are of less extent than the limestones and gneisses. The *quartzites* occur on both the eastern and western borders of the Adirondacks. In the east they are found in Essex and Warren counties; in the west they occur mainly in St Lawrence county, including the Thousand Islands area.

The *igneous rocks* of the Adirondacks are all later than the Grenville sedimentaries and, while there is doubt as to the relationships of the rocks in certain areas, in general their order has been established as gneisses, anorthosites, syenites, granites, gabbros and diabase dikes (*see* introductory chapter on rocks). The *gneisses* and *gneissic granites* are the oldest rocks in the Adirondacks and no doubt underlie the Grenville series as well as cut into them. Those in the northwestern section have been correlated with the Laurentian granites; and here also belong extensive areas of gneiss, especially in the northern Adirondacks. The *anorthosites* have an extensive development in the Adirondacks and with the exception of a few outlying areas are included in the present area of Essex and Franklin counties and cover about 1200 square miles.

Within this area are many of the highest points of the Adirondacks, such as Mount Marcy and Whiteface mountain. The *syenites* occur principally as a number of local intrusions found abundantly in the Adirondacks outside of the anorthosite area, and are especially well developed in Franklin county. The *granites* are the most abundant of the intrusives, though occupying relatively small areas and are closely associated with the Grenville series. Some characteristic exposures are those in the Thousand Islands which are known to be younger than the syenites. The age of some of the other intrusions is in doubt, and there may have been several different periods of intrusions. The *gabbros* are best developed in Essex and southern Franklin counties. Some gabbros grade into the anorthosites but others are definitely known to be younger than the anorthosites, syenites and granites. The dike rocks are the youngest of the Precambrian intrusives and the *diabase dikes* are the most abundant. They were intruded in late Precambrian time and are very numerous in Clinton and Essex counties, but less abundant on the western side and elsewhere.

The Precambrian sedimentary rocks of southeastern New York are found in the Highlands-of-the-Hudson on the west side of the river and extend in a southwesterly direction through Orange and Rockland counties into New Jersey. On the east side of the river they extend north from New York through Westchester, Putnam and Dutchess counties, passing into Connecticut. The name *Fordham gneiss* has been given to a complex series of conformable and interbedded gneisses, schists, quartzites and limestones, considered equivalent in age to the Grenville series

of the Adirondacks and Canada, which form a series of ridges, chiefly on the east side of the Hudson, north as far as the Highlands proper. Above the Fordham gneiss is a series of sedimentary formations, the *Lowerre-Inwood-Manhattan series* consisting of the *Lowerre quartzite, Inwood limestone* and *Manhattan schist.* This series has at various times been regarded as of Precambrian, Cambrian or Cambro-Ordovician age but the most recent investigations indicate a Precambrian age and the rocks are regarded as belonging to late Grenville time. Igneous intrusions, such as those found in the Adirondacks are also known in the Highlands-of-the-Hudson, though over much of the Precambrian area, especially in Orange and Rockland counties, these igneous rocks have not been differentiated from the gneisses of sedimentary origin. These intrusives include the Storm King granite and granites of similar types in adjacent areas. There are later igneous intrusions in the form of dikes, bosses and lenses which are frequent over much of this area. Excellent iron ore is very abundant in this Precambrian area, particularly in Orange and Putnam counties where the ore is magnetite, and has been extensively worked.

Literature

For the general discussion of the Precambrian eras the student is referred to any of the textbooks of historical geology as Chamberlin and Mac Clintock ('30), Chamberlin and Salisbury ('09, '30), Cleland ('16, '30), Coleman and Parks ('22), Grabau ('20), Schuchert ('24), Scott ('24) and to Schuchert and LeVene ('27). For climates, besides the textbooks may be added Schuchert ('14). A very full but technical treatment of the Precambrian of North America may

be found in Van Hise and Leith ('09). Other papers that may be consulted are Adams ('09; also in Willis and Salisbury, '10; '15), Coleman ('15), Steidtmann ('15) and Van Hise ('08; '09; also in Willis and Salisbury, '10). A number of bulletins of the New York State Museum have been written on Precambrian areas by H. P. Cushing, J. F. Kemp, J. C. Martin, W. J. Miller, R. Ruedemann etc. and the student who wishes to make a more detailed study may find these in the Museum list of publications and in Miller ('24) which is particularly recommended. For the Adirondacks are also recommended Cushing ('05) and Miller ('17). For the southeastern area of New York the reader is referred, among our bulletins, to Berkey ('07, '11, '21) ; and to these may be added Reeds ('25). In Hartnagel ('12) is found a description and classification of the New York formations. For the mineral resources of New York the student may consult Alling ('18), Colony ('23), Newland ('21 and previous reports) and Newland and Hartnagel ('28).

PALEOZOIC ERA

The name Paleozoic (*ancient life*) was given by the English geologist Sedgwick to the lower series of fossiliferous rocks resting unconformably upon the enormously thick masses of igneous, sedimentary and metamorphic rocks of the Precambrian. The name is now applied to all the series of rocks included between the end of the Proterozoic Era and the beginning of the Mesozoic Era, although fossils have been found in the Proterozoic and life in the Archeozoic is indicated and no doubt existed though too perishable to be preserved as fossils in the metamorphosed deposits of that time.

The Paleozoic is the oldest of the three main groups (Paleozoic, Mesozoic, Cenozoic) into which the normal fossiliferous strata have been divided, and in time was of vast extent, exceeding in length the combined Mesozoic and Cenozoic, according to most recent reckonings twice as long. There were widespread crustal disturbances before the beginning of the Paleozoic and there were pronounced changes again at the end of the era, so that almost universal unconformities have been produced with the Precambrian beds below and the Mesozoic strata above. Due to the abundance of fossils which furnish a reliable means of correlating formations from place to place, even between continents, the post-Proterozoic strata have been classified in much greater detail. There is no complete record of Paleozoic formations, even by piecing together all the sections studied, but it is believed with reason that the gaps left do not as a rule represent long intervals of time.

The Paleozoic group of strata has in general been divided into seven periods of time or systems of rocks: Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian and Permian, to which are now added two others, Ozarkian and Canadian (Ulrich '11), which represent respectively the uppermost Cambrian and lower

PALEOZOIC ERA

Neopaleozoic or Younger Paleozoic (characterized by the presence of vertebrates, both fishes and amphibians)		Permian*	*Late* (Age of Amphibians and Ancient Floras)
	Carboniferous	Pennsylvanian	
		Mississippian	*Middle* (Age of Fishes)
		Devonian	
Eopaleozoic or Older Paleozoic (characterized by absence of vertebrates)		Silurian	*Early* (Age of Invertebrates)
		Ordovician	
		Canadian	
		Ozarkian	
		Cambrian	

* Lower Permian in North America is regarded by some as the top of the Pennsylvanian; the Upper Permian as Mesozoic.

Ordovician of authors. These periods are not of equal length, nor have they been of equal importance in the development of life. They can be recognized in any part of the world by their characteristic fauna, and it is upon these faunas that their separation is ultimately based, though locally the systems of rocks may often be clearly marked by unconformities. As shown in the table above, in the older Paleozoic series of rocks no vertebrate remains are found at all. They are found for the first time in the Silurian, and even those are doubtful vertebrates. Invertebrates are just as abundant in the younger as in the older Paleozoic even though characterized by the higher forms of life.

The rocks of the Paleozoic are conglomerates, sandstones, shales, and limestones and dolomites with quite extensive areas of metamorphic rocks and associated igneous masses, but on the whole Paleozoic strata are far less altered and deformed than those of the preceding eras. In Europe the estimated total thickness of Paleozoic sediments is about 100,000 feet, though of course not in any one place. In North America the greatest thickness is exposed in the much folded and profoundly denuded Appalachian Mountains area. The maximum thickness of marine deposits of all kinds in our continent is approximately 75,000 feet, which has been estimated as equivalent in time of depositions to 43,000 feet of limestone. North America is wonderfully rich, particularly in the eastern half of the United States and Canada, in the long succession of Paleozoic formations with abundant fossils; and here in contrast to Europe, the highly fossiliferous strata west of the Appalachian area in the Mississippi valley and in southern and medial Canada occur in almost the same position in which they were

deposited and have yielded numerous fossils. The famous Paleozoic sequence in New York State has been the "*standard section*" with which the Paleozoic rocks of America have been compared and correlated, although it is now known that this section is far from complete, being interrupted by numerous breaks or erosion intervals that are represented by deposits elsewhere.

The North American continent was outlined in much its present form during the early part of the Proterozoic, and at times was even larger than it is today. It extended for several hundred miles into both the Atlantic and Pacific and was connected then, and for a long time subsequently, by dry land with northwest Europe by way of Greenland. There were certain areas of depression, narrow troughs or synclines (called geosynclines from Greek *gea*, earth), which remained seaways for long periods of geologic time and in which were accumulated heavy deposits of sediments. One of these depression troughs was in the eastern part of the continent running northeast-southwest; the second in the western part, extending north and south; and the third was in the middle part of the continent extending roughly east and west. There was an Arctic seaway in the northwest also which partook of the nature of a shallow continental sea, such as Hudson bay today, rather than of a depression trough or syncline. The sediments making up the conglomerates, sandstones and shales (known as clastic sediments or clastics) were derived from the bordering lands. In general the Proterozoic was a time of continental elevation. During the period of mountain building at the close of the Proterozoic the mainly continental deposits of the medial geosyncline were folded up into mountains (Killarney mountains) which divided the interior of the con-

tinent into a northern (Canadian Shield) and a southern (United States and Mexico) plain. These mountains were reduced almost to sea level (peneplane) near the close of the Ordovician, making of the interior of the continent one vast plain which was transgressed by seas again and again during Paleozoic and in late Mesozoic time.

The Paleozoic era opened with the continent much as in the Proterozoic. Both the Atlantic and Pacific oceans were in existence though probably much shallower than today and broader despite the fact that the continent extended for some distance into the oceans on the east and west. The Arctic ocean was also in existence at this time though fossils indicate that the waters were at times much warmer than now. This era was a time of oscillatory movements, that is, certain areas were at times elevated and then again depressed, giving the extensive development of seas over the continent which was such a characteristic feature of the Paleozoic. There were also certain dominant land masses or positive elements, quite distinct from the dominant land areas of today, which remained land more or less constantly, and certain areas of more or less continuous subsidence, interrupted in some cases, and in general parallel to the principal land masses from which was carried to them a more or less constant supply of clastic material or sediments.

The several seas which transgressed the continent due to alternating depression and elevation of the land were such as are seen today in Hudson bay and the Baltic sea. For the most part they were shallow and covered large areas of the continent as it exists today, and hence have been variously termed *continental, epicontinental* (Greek *epi,* upon) or *epeiric* (Greek *epeiros,* mainland) *seas.*

These continental seas were extensions of the great oceans and several could occupy the continent at the same time, each from a separate ocean. Just as today, each ocean was characterized by its peculiar fauna and flora, though certain types might occur in two or more of the oceans. Each continental sea carried the fauna of the ocean of which its waters were an extension. When the continental seas remained distinct their faunas remained more or less distinct, and when they became confluent there was, rarely, a commingling of the faunas carried by each. Commingling of faunas in this way occurred only very seldom. There is no evidence of commingling after the Ozarkian and the best instance of it seems to be the Upper Ozarkian fauna. Apparently intermingling of faunas of distinct origin came about through occasional submergence of barriers in areas now covered by the Atlantic and Pacific oceans. Sometimes a continental sea might be more or less cut off from the ocean from which it had its source and the fauna which it carried, thus isolated, slowly became modified until a distinct fauna was developed in the restricted area. With the spreading of the seas again such a fauna might become widely distributed, more or less cosmopolitan.

The *geosyncline belts* or areas of depression were for the most part long and comparatively narrow. Though subsiding continuously they were not always covered by the shallow continental extensions of the oceans; sometimes, in part at least, they were above water and the deposits they received were of a continental nature. In some cases they passed into the shallow continental seas in a direction away from the oceans, or again they might be narrow troughs or seaways bordered on both sides by land masses. It was in these geosynclines that the thick-

est deposits of Paleozoic time were laid down and in the Appalachian Mountains area, which is the type region for geosynclines, the Paleozoic sediments reached a total thickness of over 60,000 feet. In all cases deposition in the geosynclines was terminated by foldings of the strata deposited and both during and at the close of the Paleozoic they were the sites of the principal mountain folds.

It was the positive elements or *dominant land masses* which were the source of the bulk of the clastic material that was deposited in the geosynclines and continental seas and upon the lowlands. Certain of these land masses should be mentioned here. Most prominent in eastern North America is the one to which the general name of *Appalachia* has been given. This land area in general was situated along the eastern border of the continent and extended for an unknown distance into the present Atlantic ocean. Its western limit was the present Piedmont belt of the southern Appalachians, the Florida platform covered by younger deposits and part of the New England and Newfoundland uplands in the north. It extended continuously from Newfoundland on the north to the Brazilian oldland of South America and beyond on the south. The central axis of Appalachia was probably located somewhere near to or outside the present eastern margin of the continent, and that it was of mountainous heights is indicated by the amount of sediments derived from it. Appalachia was the source of practically all the clastic materials which make up the Paleozoic deposits of eastern North America. On its western border was a narrow arm of the sea or seaway, the Appalachian geosynclinal trough, which received the bulk of the clastic material derived from Appalachia and whose sediments toward the close of the Paleozoic were

involved in a period of mountain building which produced the Appalachian mountains. This seaway on the north was sometimes open to the Arctic region, also to the North Atlantic through the New England and Newfoundland region at which time these waters with their faunas also entered parts of the geosynclinal trough. In New England and the maritime provinces of Canada long, narrow strips of land alternated at times with narrow sounds. In the west was a land mass also important but less well known, *Cascadia.* It occupied the western border of North America and extended for an unknown distance into the present Pacific ocean. The narrow seaway of the Cordilleran geosyncline separated it from the main continent and at its greatest extent reached from southeastern California to the Arctic ocean. In this geosyncline or area of more or less continuous depression were laid down the principal western Paleozoic deposits which toward the close of Paleozoic time were folded into the Paleozoic Cordilleran Mountain chain. From this Cordilleran seaway the waters of continental seas spread eastward while the waters from the Appalachian seaway spread westward. Sometimes the two geosynclines were in communication by means of a transverse geosynclinal trough extending through Arkansas and the southern Gulf states. The *Canadian Shield,* that oldest portion of the North American continent bordering Hudson bay, has already been mentioned under the discussion of the Archeozoic and Proterozoic eras (p. 198) and its peneplanation (Laurentian peneplane) at the close of the Archeozoic pointed out. In Paleozoic times this area constituted a central, low-lying land formed by the surface of the old Laurentian peneplane and its later modifications. Continental seas expanding from the geo-

synclines repeatedly flooded this area, and at times there was a transgression of the sea from Arctic regions also. It was apparently by way of this channel that communication was maintained with European seas.

The physical geography of ancient periods, that is, the relative distribution of land and water areas, has been shown on a series of maps known as *paleogeographic maps* (Green *paleos,* ancient). The determination of the distribution of land areas in these ancient times is a difficult matter and therefore the outline of the lands, oceans and seas are only approximately known. Paleogeographic maps are based upon the character of the deposits taken into consideration with the distribution of the fossil marine faunas and formations as shown on geologic maps.

Cambrian and Ozarkian Periods

The name Cambrian was first proposed (1835) by the Rev. Adam Sedgwick, Professor of Geology in Cambridge University, England, for the oldest stratified rocks of North Wales. The name was derived from the Roman name for the region, the province of Cambria. Here the Cambrian strata have an estimated thickness of 20,000 feet; but if translated into terms of the Cambrian as defined in America the thickness would be much less than this, and indeed it is doubtful whether even including the Ozarkian the strata would be as thick as this. In 1911 the name Ozarkian was proposed by Ulrich (from the Ozark uplift in Missouri) for a great series of formations previously regarded as passage beds between the Cambrian and Ordovician. These formations will therefore be found variously classified by different authors. By some they are accepted as the Ozarkian series and

considered as representing the uppermost Cambrian deposits.

Geology. The *Cambrian* is the oldest period of the Paleozoic era, generally separated from the older rocks by the most marked unconformity, representing a very long interval of erosion. Except for the few fossils found in the Proterozoic this is the oldest fossiliferous system yet known. At the opening of the Cambrian all known continents were dry land and subject to erosion, and it was during this period that the first great transgression of the seas over the continent occurred. Practically everywhere both in North America and in Europe all Cambrian series of rocks resting upon older rocks begin with a basal sandstone or conglomerate. The deposits of residual sands, the product of long continued erosion, were reworked by the transgressing seas and formed the first deposits, which were generally a pure quartz sand. In cases where the deposits were very thick the seas could only rework the upper portions leaving intact the lower portions with their original structures which may be torrential or eolian. The first sediments of the Cambrian were not always marine, either, for before the transgressing sea reached certain areas, as the southern Appalachians, great quantities of sands and pebbles were deposited by the rivers in the form of beach deposits. In their essential features the Appalachian and Cordilleran geosynclines, or sinking areas, were already in existence in the Cambrian, and in general there was an advance of continental seas by shifting of old seas throughout Cambrian time, though there were also periods of retreat with erosion, followed by advance again in varying directions. The shifting of seas is illustrated by the distribution of the deposits. The Lower Cambrian deposits stretch from

eastern Canada to Alabama, but are confined to the eastern part of the geosyncline. Middle Cambrian deposits with *Paradoxides* occur in northern Vermont and in Newfoundland and eastern Massachusetts. Some of the Arctic and Cordilleran Middle Cambrian faunas passed south from east Canada to Alabama in more western troughs, now doubtless buried under overthrusted deposits in most of the St Lawrence valley and all of eastern New York but exposed from Pennsylvania southward. The Upper Cambrian is absent north of central Pennsylvania but northern types occur in southern Pennsylvania and southern types are found in great development from southern Virginia to Alabama. Late Upper Cambrian occurs only in and to the west of the Mississippi valley. The great difference in thickness of the formations of Cambrian deposits in different regions, which varies for the period from a few hundred to 12,000 feet, is mainly due to the oscillating seas and the relative availability of the clastic materials.

The greatest deposits of Cambrian rocks in North America were laid down in the Cordilleran trough, and their remnants which are found today in southeastern California, Nevada, the mountains of Utah and the Canadian Rockies constitute the most extensive and most complete series in the world, yet known. They were made the subject of prolonged study by the late Dr Charles D. Walcott, leading student of Cambrian faunas and their sequence. In the Appalachian trough the rocks of this system show a greater thickness to the north and south of the eastern New York area. In the north the most noted localities occur in western Newfoundland and on the shores of Labrador, the deposits of which are in accord with and may at one time have been continuous

with those of northern Scotland. From New Jersey and Pennsylvania south to Alabama the deposits of the Appalachian trough have been profoundly disturbed. On the Atlantic side of Appalachia the Cambrian deposits have an Atlantic fauna and the series shows a clear correspondence with that of Sweden which also belongs to the Atlantic province. Remnants of these deposits occur in eastern Massachusetts, New Brunswick, Cape Breton and Newfoundland. Cambrian rocks are also found in the interior bordering the older crystallines where they appear at the surface. Although patches of outcropping Cambrian rocks are of wide extent in North America many deep wells that have penetrated to the Precambrian floor show that their extent under cover of younger strata is much more limited than was formerly believed.

In eastern North America the Lower Cambrian is restricted to the Appalachian geosyncline and these rocks have been called the *Taconian series* because they were first studied and recognized as a system in the Taconic mountains of eastern New York by Prof. Ebenezer Emmons of the New York State Survey. This series was previously termed Georgian from Georgia, Vermont, where Lower Cambrian beds occur. The Lower Cambrian sediments of the Appalachian trough show great thicknesses in places. They are thickest in the south suggesting that the trough was invaded from the south and transgression took place northward with accompanying overlap of successive horizons. In Vermont and northeastern New York there are about 3000 feet, 1500 feet consisting mainly of slates and quartzites and 1200 feet of marble and dolomite. Through Pennsylvania, Maryland, and Virginia

there is a total thickness of approximately 10,000 feet, about half sandstones and shales and half limestones. The Cambrian series in this Appalachian trough often begins with conglomerates and sandstones of continental origin and the finer shale material is encountered as one goes westward. Other sections show mainly limestone upon the basal sandstone, but such deposits could be formed only in those portions of the trough beyond the reach of sediments washed from the lands. The Lower and Middle Cambrian deposits on the Atlantic side of Appalachia (the Atlantic province) occur in eastern Massachusetts, New Brunswick, Cape Breton and eastern Newfoundland. These beds are several thousand feet thick in Cape Breton. There is a progressive overlap toward the oldland and the beds thin out, being wholly wanting or replaced by continental deposits at St John, New Brunswick, where the marine Cambrian deposits begin with the Middle Cambrian. The best representative of the Lower Cambrian, as well as of the Cambrian as a whole, is found in the region of the Cordilleran trough, the deposits of which were derived from the Cascadian land mass to the west. One of the thickest sections measured, of about 6000 feet, was found in the Cordilleran trough near Waucoba Springs in Inyo county, California, hence the Lower Cambrian in the west has been called the Waucobian series. These deposits are largely sands, often Proterozoic residuals worked over by the advancing sea. There is a continuous overlap of beds eastward, and they are much thinner in Nevada and the Great Basin region. In the Appalachian trough the marine waters were largely withdrawn toward the close of the Lower Cambrian, and the sea did not claim

it again until Upper Cambrian time, and there was a long interval of erosion before the introduction of a new cycle of deposition.

Throughout Middle and Upper Cambrian times the continent of North America was a lowland, permitting the seas to encroach widely upon the lands. Highlands, if any, were to be looked for only in the borderlands of Cascadia and Appalachia. The Killarney mountains in the center of the interior lowland were reduced to a low upland. Since the greater part of the Appalachian trough was not occupied by marine waters, here the Upper Cambrian beds, where present, rest as a rule upon Lower Cambrian (southern Appalachian region). As we have seen, the seas of the Lower Cambrian were restricted to the two great troughs or geosynclines. During the Middle Cambrian the eastern trough was largely drained of Atlantic waters, but once or twice during this epoch marine waters teeming with life common to the western (Cordilleran) trough spread eastward into it. In Upper Cambrian times continental seas of wide extent, with faunas mainly of western origin, were developed, especially in the Mississippi basin. However, the Upper Cambrian faunas of the southern Appalachian region are mainly of Atlantic origin and very different from the western life of the same epoch.

The Middle Cambrian beds in the east are particularly well developed in the Acadian region of eastern Canada and hence this series of beds is known as the *Acadian series*. The marine waters then occupying this region belonged to the Atlantic Province. The deposits consist mainly of shales although there are some thin limestone beds. There is very little sand

except at the top of the series. Occurrences have been found as far south as eastern Massachusetts (Braintree). Middle Cambrian beds have also been found in eastern New York (p. 237) and in northern Vermont.

The Middle Cambrian beds of the Cordilleran trough belong to the Pacific Province and carry an entirely distinct fauna from those of the Atlantic. Here are found the best Middle Cambrian sections and only here are there transition faunas between Middle and Upper Cambrian. Elsewhere the absence of transition faunas indicates a break in deposition (eastern America). At Alberta, Canada, 8300 feet of deposits have been measured, mostly limestone, but including some beds of shale such as the seven-foot thick Burgess shale which through the labors of the late Doctor Walcott has furnished a remarkable fauna of crustaceans, worms, holothurians (sea cucumbers) etc. which have not been seen elsewhere. The sea continued to transgress through the Middle Cambrian, and through Utah, Montana and elsewhere in the northwest the first Cambrian beds of marine nature belong to the middle epoch. The Upper Cambrian is also known as the *St Croixian epoch* from its occurrence in the St Croix river region of Wisconsin. This series of beds will be found in many earlier works classified as early Upper Cambrian with the beds of the lowest series of the Ozarkian system representing the final series or uppermost Cambrian. The St Croixian of the upper Mississippi valley includes the youngest true Cambrian known, that is, the Cambrian as developed in America by Walcott and Ulrich. The three upper formations there are rarely or not at all represented in the Appalachian valley. The seas spreading eastward from the

Cordilleran trough were of wide extent during this epoch, especially in the Mississippi basin, and these waters of mainly Pacific and Arctic origin at times also entered the southern part of the Appalachian trough. The uplands of the Killarney mountains prevented these waters from spreading north of the Lake Superior-Lake Huron region. The deposits of this time in the Cordilleran trough and the southern Appalachians range in thickness from 3000 to 4000 feet, most of the material being limestones. The Upper Cambrian in the Arbuckle mountains is less than 500 feet thick and largely of sandstone. In the strata of the upper Mississippi valley sandstones predominate and these were derived from the residual material formed by long-continued erosion of the crystalline low land of the Canadian Shield. The Upper Cambrian of the Atlantic Province (*Bretonian*) has its greatest thickness in Cape Breton and the New Brunswick region. The Upper Cambrian as defined here does not appear in the northern part of the Appalachian trough.

The *Ozarkian system* of rocks is separated from the Upper Cambrian (St Croixian) beds by a break or unconformity and is marked by a great difference in the character of the fauna. Deposits of the period have been found outcropping from New York and Vermont south through New Jersey and Pennsylvania to Alabama, in the Mississippi basin (Missouri, Iowa, Wisconsin, Minnesota, Oklahoma), central and western Texas, Colorado, Idaho and Nevada. They have also been found in British Columbia and it is believed with good reason that the system is represented in western Quebec and possibly northern Newfoundland. The Lower Ozarkian sea invaded the continent by

separate entrances and probably at different times from the south, the east and the northwest, and spread into the Appalachian trough extending northward into New York and Vermont and thence through the St Lawrence area of Canada. The Cordilleran trough was also invaded, but, since the Lower Ozarkian faunas of the Mississippi valley and New York are almost totally different, the former was evidently invaded from the Arctic side of the continent. The Cordilleran formations are all of Lower Ozarkian time. In late Ozarkian time the seas were greatest in the southern part of the Appalachian trough and the Mississippi valley. The Ozarkian deposits are chiefly dolomites and relatively pure limestones and these deposits in the southern Appalachian valley alone aggregate about 8000 feet, giving a volume of limy deposits that on the basis of thickness alone would rank the Ozarkian among the most important of the Paleozoic systems. At the very close of the Ozarkian period the continental seas appear to have withdrawn widely from the interior of North America. There was a period of land elevation which, because it involved the Green Mountains area of Vermont, has been termed the Green Mountain Disturbance. Through the formation of these highlands a period of erosion was inaugurated. They supplied the materials which go to make up the basal conglomerates of the following period, the Canadian, which is set off from the Ozarkian by an unconformity.

Life. In the discussion of the life of these periods it must be remembered that there are two faunal provinces to be considered, a *Pacific Province* and an *Atlantic Province*. The Pacific Province was the larger in North

America and its waters spread across the continent and even entered the Appalachian trough, which therefore belonged to the Pacific Province. The Atlantic Province was separated from the Appalachian trough by the land mass of Appalachia which appears to have extended through the center of Newfoundland since deposits of the Pacific Province are here found in the western part and those of the Atlantic Province in the extreme east.

Trilobites were the dominant form of life of the *Cambrian* and made up the largest element of the fauna, the brachiopods holding second place. So characteristic are the trilobites that their names have been used to indicate the divisions of the systems which they characterize, as Lower Cambrian or *Olenellus fauna,* Middle Cambrian or *Paradoxides fauna,* Upper Cambrian or *Dicellocephalus fauna.* This is to a certain extent misleading and must be qualified since some genera are characteristic of the Pacific Province and others of the Atlantic Province. In the Pacific Province the Lower Cambrian is characterized by species of *Olenellus,* the Middle Cambrian by *Olenoides* and the Upper Cambrian by *Dicellocephalus*; while in the Atlantic Province the equivalent divisions are characterized respectively by *Holmia, Paradoxides* and *Olenus.*

The fact that in the Cambrian are representatives of the highest forms of invertebrates, the crustaceans, indicates that life was well-developed before the Cambrian and must have developed in that period of time between the Proterozoic and Cambrian which has left no depositional record on our present land areas, and is marked by a practically universal unconformity. *Plants* must have been in existence in large numbers

in order to supply food for the abundant marine life of the time. Algae or seaweeds secreting lime played an important part in the formation of some of the Cambrian limestones. All the main stocks of invertebrate life are represented in the Cambrian fauna which ranges from simple sponges to highly developed crustaceans. The trilobites were the most striking forms of life of the period but a number of other crustacean groups, representatives of which live today, were found in the Middle Cambrian (Burgess shale) of British Columbia. The *brachiopods* came next to the trilobites in abundance. There are two divisions of the brachiopods: (1) with hingeless and horny (phosphate of lime) shells; (2) with calcareous shells and well-developed hinges. Representatives of the first or more primitive division are more abundant in the Cambrian; of the second division, in the later Paleozoic. Twenty-two Lower Cambrian brachiopod genera have been described for Europe and North America. Brachiopods as a class are important throughout the Paleozoic and make good index fossils because of the abundance of individuals and because so many species have a short vertical range, that is, are confined to one period or a subdivision. No true *pelecypod* or *mussel shells* are known in beds older than Ordovician (St Peter sandstone). Shells so classified hitherto are crustaceans. *Gastropods* were represented by the cap-shaped or patelloid forms and also coiled forms. Real patelloids and coiled Bellerophontids and the peculiar left-handed (sinistral) coiled *Scaevogyra* came in for the first time in the youngest of the fossiliferous Cambrian formations (Trempeleau of Mississippi valley). The typical *Scenellas* of the Lower Cambrian have no unquestion-

able warrant to be called gastropods, and *Stenotheca,* too, is probably a pteropod or heteropod. Except for a small, primitive type (*Salterella*), cephalopods are missing, and this is a very doubtful form, not accepted by Ulrich and Foerste. The *conularids* are abundantly represented by the three-sided tubes of *Hyolithes* *Echinoderms* are rare but are represented by primitive cystoids and crinoids, and remains of sea cucumbers have been found in the Middle Cambrian (Burgess shales). *Worms* are abundantly represented by burrows and trails, and in the fine Burgess shale fleshy parts have been preserved as a glistening surface showing fine detail. *Sponges* were represented by several genera and are somewhat abundant in certain parts of the Cambrian. They are known by their silicious spicules. *Jellyfishes* occurred and are common fossils in some places, as in the Lower Cambrian of Vermont. *Corals* or coral-like forms (Archaeocyathidae), which have sometimes been described as corals, again as sponges, were rare in general throughout the period but were locally abundant and in many parts of the world built up limestone reefs as in the Lower Cambrian of Inyo county, California. Of the 1500 Cambrian species known from all parts of the world considerably over 1000 have been described from North America alone, and of the total number of species trilobites and brachiopods together make up fully 90 per cent in the proportion of two to one in favor of the trilobites. There are 500 undescribed species in the U. S. National Museum, and 100 of these will be in print soon, perhaps before the close of 1930 (Ulrich).

The Lower Cambrian fauna was *cosmopolitan* in character since the life of this epoch was much the same

all over the world. The trilobites were its most characteristic animals. Nearly all the brachiopod shells were horny and the limpetlike shells commonly classified as gastropods. The corallike animals were almost restricted to this epoch. The life of the Middle and Upper Cambrian showed greater variety but, as in the Lower Cambrian, was chiefly trilobites and brachiopods. The faunas were no longer cosmopolitan but with the Middle Cambrian two realms or provinces are recognized, that of the North Atlantic or *Acadian* and that of the Pacific or *Albertan,* both of which have been discussed above. Both trilobites and brachiopods of the Middle Cambrian of the Cordilleran area were more numerous than in the Lower Cambrian, the trilobites constituting about half the faunas. Trilobites showed greater variety and among the genera found were *Bathyuriscus,* the most prevalent form, *Olenoides, Neolenus, Ogygopsis* etc. The Burgess shale in the Canadian Rockies, near Field, British Columbia, has yielded a collection of organisms including worms, sea cucumbers, jellyfishes, and a most interesting array of crustaceans (branchiopods, phyllocarids, primitive and specialized trilobites etc.). The Acadian or Middle Cambrian fauna of the Atlantic Area, known as the *Parodoxides fauna,* because characterized by that trilobite genus, has a distinctly different character, showing a similarity to the fauna of western Europe which also belongs to the Atlantic realm. The Upper Cambrian (St. Croixian) epoch has also its characteristic trilobites, among them *Dicellocephalus, Illaenurus* and *Crepicephalus.* Eurypterids occur here for the first time. Brachiopod genera with calcareous shells are more frequent and coiled gastropods have appeared.

The *Ozarkian period* is particularly marked by the advent of cephalopods and a preponderance of molluscan life. The *Dicellocephalus* fauna persisted, and other derivations of Cambrian *trilobites* are no less characteristic of the Ozarkian. *Cephalopods* (100 species), coiled and true patelloid *gastropods* and also true *cystids* became prominent for the first time in the Ozarkian. Gastropods have begun their ascendancy and are represented by a fairly large number of genera. It is the occurrence of a host of true gastropods and cephalopods, of types entirely unknown in the true Cambrian rocks, that stamps the Ozarkian as a new period in geologic history. The cephalopods became abundant at some time in Missouri (Gulf fauna), but somewhat later than the gastropods in Oklahoma (Pacific). Pelecypods or bivalved mollusks and ostracods among the crustaceans are wanting. Ozarkian fossils are difficult to collect because most of the formations are dolomitic. On silicification of the matrix, however, good pseudomorphs are readily procurable. One hundred and twenty-five species have been listed, and a great many more than this are known and in course of description by Ulrich. The most prevalent organisms of the Ozarkian were *calcareous* (lime-secreting) *algae* or seaweeds, known as *Cryptozoön,* occurring as reef beds in the Hoyt limestone and Little Falls dolomite, and strikingly exposed in Lester Park and elsewhere in the Saratoga area in New York.

Climate. The widespread occurrence of the reef-making corallike animals of the Lower Cambrian, and also the great numbers of individuals and variety of species found among the trilobites and other classes

of animals indicate a warm and uniform climate over most of the earth. The greater abundance of life and the very thick limestone deposits of the middle and later epochs are evidence that there was a mild and fairly uniform climate over the entire world during the whole period. This is true also for the Ozarkian period with its 8000 feet of deposits almost entirely limestones and dolomites.

New York formations. The Upper Cambrian is not represented at all in New York State and the Middle Cambrian has but little representation. The formations of the Saratogan group are now known to represent the Lower Ozarkian. The Wappinger terrane in southeastern New York will be treated separately, after the discussion of the other formations, since it consists of several members containing faunas of Lower Cambrian, Ozarkian, Canadian and Ordovician ages. The formations of the Cambrian and Ozarkian are classified as follows:

Ozarkian System (Lower)		Little Falls dolomite
		Hoyt limestone (basal phase of Little Falls)
		Theresa formation; passage beds
		Potsdam sandstone
Cambrian System	Middle	Stissing limestone
	Lower	Georgia beds
		Poughquag quartzite

The *Poughquag quartzite* (quartzite and conglomerate) occurring in southeastern New York, received its name from exposures at Poughquag (Dana '72) in southern Dutchess county. It rests unconformably upon the Precambrian rocks below and, as is commonly the case with the first sediments overlying the Precambrian basement, it is a pure quartz rock

formed from sands resulting from long-continued weathering of the crystalline floor. The Poughquag is a well-cemented, exceedingly resistant quartzite conglomerate in places, appreciably felspathic, and varying in color, white (slightly yellow with iron stain), blue gray, and mottled pink, yellow and white being the commoner types. The rock is developed in beds approximately 600 feet in thickness. The quartzite also outcrops in Orange county where the formation shows greater coarseness. *Olenellus,* brachiopods resembling *Obolella* and *Scolithus linearis* (worm tubes), have been listed from these beds, thus establishing its Lower Cambrian age.

The *Georgia beds* were named (Hitchcock '61) from the occurrence at Georgia, Vermont, and the name was later applied to the series which has more recently been termed the Taconian series. These beds are still currently known as the Georgia beds but they are now divided (Ruedemann '14) into a number of formations (*Bomoseen grit, Mettawee slate, Eddy Hill grit, Schodack shales and limestone, Nassau beds, Diamond Rock quartzite, Troy shales, Zion Hill quartzite*) which total a greatest thickness of about 1500 feet, of which 200 feet are formed by the Bomoseen grit, 250 feet by the Schodack shales and limestone (figure 24), 800 feet by the Nassau beds (figure 23) and 100 feet by the Troy shales. The Schodack shales and limestone have furnished the largest fauna. The beds in New York are *Olenellus*-bearing shales and slates, quartzites and brecciated limestones which occur in the highly folded and metamorphosed region east of the Hudson river in the counties bordering southern Vermont and Massachusetts. The shales and slates are greenish

Figure 23 Lower Cambrian rocks. Red slate and alternating quartzite of the Nassau beds along the state road between Brainard and Nassau, Rensselaer county. (Photograph by E. J. Stein)

Figure 24 Lower Cambrian rocks. "Edgewise" breccia in Schodack shales and limestones on road between Snyder's lake and Defreestville-West Sand lake road, Rensselaer county. (Photograph by E. J. Stein)

gray, red and purple. The most prevailing rock is the dark, greenish gray silicious shale or slate which appears to serve as a ground mass in which all the other rocks, quartzites, red and purple shales, limestones and sandstones, are distributed. These rocks show a very much folded structure and are of unequal hardness.

The *Stissing limestone* was named (Walcott '91) from its occurrence in Stissing mountain in northern Dutchess county. The beds overlie the *Olenellus*-bearing beds. It has been suggested (Ulrich) that the somewhat doubtful Middle Cambrian sediments occurring in Stissing mountain originally belonged farther to the east and were moved westward to their present position by a thrust fault.

The Ozarkian system of rocks (figure 25) rests upon the Precambrian crystallines from which it is separated by an unconformity. New York State evidently was very largely land during Cambrian times. The first important Paleozoic submergence of the southern flanks of this area came during the Ozarkian period with the Potsdam or Saratogan submergence.

The *Potsdam sandstone* (figure 26) is the basal member of a new cycle of deposition which was continuous through the Little Falls dolomite. Potsdam deposition started in the Champlain trough toward the northern end and worked southward in that trough and westward up the St Lawrence trough. It is believed unlikely that the eastern and western lobes of this sea connected across the southern part of New York before the closing stage of the Potsdam. The Adirondack area which was much reduced by erosion and general subsidence then became an island until just preceding the Little Falls dolomite stage a warping uplift

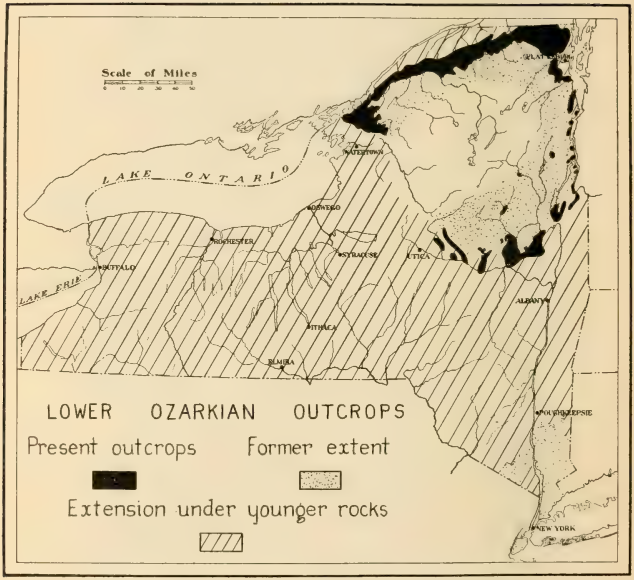


Figure 25 Lower Ozarkian outcrops. The probable former extent of the seas of this period and the extension of the formations under those of younger age are shown.

raised the northern and western flanks of the island restricting the sea to the Champlain trough in the east and the Mohawk basin on the south. The Potsdam sandstone (Emmons '38) was named from typical exposures in the vicinity of Potsdam in St Lawrence county. The most extensive development occurs in the northern part of the state bordering the Adirondacks; the areas on the eastern and southern boundaries of these mountains are less extensive and discontinuous. Sections showing a representation of all the formations from the Potsdam through the Little Falls dolomite may be seen at Ticonderoga, Whitehall, Saratoga Springs and in the Mohawk valley at Cranesville, Tribes Hill and Broadalbin. Southward from Saratoga the Potsdam sandstone rapidly thins and disappears, probably due to overlap of later beds. The sandstone everywhere abounds in ripple marks showing its shallow-water or near-shore origin. It constitutes all the rock in the walls of the famous Ausable Chasm. The Potsdam is a light-colored, vitreous sandstone carrying occasional calcareous layers in the upper portion and with more or less coarsely conglomeratic beds at the base. The thickness is variable because of the irregular erosion surface of the Precambrian beneath but from sections and borings the maximum thickness has been estimated as over 1500 feet. In its lower portion it was probably a continental deposit but the upper portion carries a marine fauna which continues through the Theresa passage beds into the Little Falls dolomite.

The *Theresa formation* (Cushing '08) received its name from exposures in the town of Theresa, Jefferson county, and as first described included the passage

Figure 26 Lower Ozarkian rocks. The Potsdam sandstone at Ausable Chasm, Essex county. (Photograph by J. A. Glenn)

beds and the overlying magnesian limestones occurring between the Potsdam sandstone and the Pamelia limestone. The limestones have been correlated with the Tribes Hill limestone (Lower Canadian), but the name has been retained for the passage beds between the Potsdam sandstone and Hoyt limestone or Little Falls dolomite which are missing in the type section. The succeeding dolomites of the Canadian period also are missing in this section so that the Tribes Hill is in contact with the Pamelia limestone. The passage beds have a characteristic lithology of their own. They consist of alternating beds of hard vitreous sandstone; gray calcareous sandstone; blue or gray crystalline dolomites and magnesian limestones; black, oölitic beds in some sections, blackish, crystalline, sandy limestone in others. These beds have a maximum thickness of 80 feet and contain trilobites and *Lingulepis acuminata.* They occur everywhere in New York between the Potsdam sandstone and Little Falls dolomite.

The *Hoyt limestone* is a more calcareous and more fossiliferous phase of the lower portion of the Little Falls dolomite, and is regarded as merely a local member. The name was proposed (Ulrich and Cushing '10), in place of the name "Greenfield" which was preoccupied, from the Hoyt quarry section near Saratoga. The formation is mainly a dark gray or blackish, finely crystalline or subcrystalline limestone with alternating beds of blue and light gray dolomite. Beds of calcareous sandstone and more rarely quartzose sandstone occur. Beds of black oölite occur most abundantly near the base. Reefs of the calcareous alga, *Cryptozoön,* characterize this formation, also the trilobites *Tellerina hartii, Saukia*

speciosa, Plethopeltis saratogensis etc. (respectively, *Dicellocephalus, Ptychaspis* and *Agraulos*). Trilobites, gastropods and *Lingulepis acuminata* occur at many horizons. The Hoyt formation has been found at several localities in Saratoga and Washington counties, and the fauna of this horizon has been found in the Wappinger terrane of southeastern New York (Dutchess and Orange counties).

The *Little Falls dolomite* (Clarke '03) was named from the type locality at the pass in the Mohawk valley at Little Falls, Herkimer county. It was previously placed in the Beekmantown formation and therefore considered as Lower Ordovician (= Canadian), but later studies have shown it to be the uppermost member of the Lower Ozarkian series in New York State and to be separated from the rocks of the Canadian system above by an unconformity. This formation is a light gray to dark gray crystalline or subcrystalline dolomite. Black and gray cherts are found frequently at certain horizons, and certain layers are full of nodules of crystalline calcite. The summit is very apt to be formed of a massive *Cryptozoön* reef, often heavily silicified. The maximum thickness of this formation is about 200 feet. Except for the *Cryptozoön,* fossils are very scarce. This formation occurs with the rest of the Ozarkian series at the east and south of the Adirondack area, but continues farther to the west in the Mohawk valley, extending beyond Tribes Hill to Little Falls and Newport and, because of the absence of the other beds, resting upon the Precambrian. The Potsdam shore must have had a more southerly trend in this area, that is, the Little Falls subsidence covered more of the southern part of the old land area than the Pots-

dam. Warping and differential uplift followed the Little Falls deposition, causing the retreat of shore lines followed by erosion resulting in the unconformity at the top of the Little Falls.

The *Wappinger terrane* comprises a large development of dolomitic limestone with a total thickness of approximately 1000 feet, and is termed a terrane because several fossil zones have been recognized representing the Lower Cambrian, the Potsdam and Hoyt horizons in the Ozarkian system and the Beekmantown and lower Trenton in the Canadian and Ordovician systems respectively. That is, this development of limestones consists of several members separated by gaps in deposition. These limestones occur in Dutchess, Orange and Ulster counties and have also been traced into Columbia county. The beds lie above the Poughquag quartzite and below the "Hudson river" slates. The Wappinger limestone received its name from its occurrence along Wappinger creek in Dutchess county (Dana, Dwight '79). It is a compact, massively bedded, dolomitic limestone of three types: (1) a light gray, fine-grained variety, the prevailing type; (2) a darker bluish gray, coarsely crystalline variety; (3) a crystalline conglomerate. In practically all outcrops the limestone is conspicuous for its brecciated character due to the fractured nature of the rock. The prevailing light gray, fine-textured limestone has been generally considered of Beekmantown (Canadian) age; the dark bluish gray, coarsely crystalline limestone contains fossils of Trenton (Ordovician) age. The conglomeratic limestone marks the break between the Beekmantown below and the Trenton above. A study of its fossils indicates that the break marks the time immediately preced-

ing the Trenton, late Black River, or the earliest stage of the Trenton itself. The limestones in Orange county have been shown to contain fossils of Potsdam as well as of Trenton age and west of Newburgh a limestone has been found that looks very much like the Hoyt limestone and contains a Cryptozoön-like marking. On the Poughkeepsie quadrangle the limestone rests conformably above the Poughquag quartzite and contains a fauna of Lower Cambrian age. A similar limestone occurs on the Newburgh quadrangle, and south of this area a Beekmantown fauna has been found.

The Wappinger limestone has also been described as the *Barnegat limestone* (Mather '38) from Barnegat (now Stoneco) in Dutchess county. An extensive area of this limestone developed just north of the Fishkill mountains has been called the *Fishkill limestone* (Gordon '09) and is in part equivalent to the Wappinger. The limestone has also been described as the *Neelytown limestone* (Horton '39) from Neelytown in Orange county, and the limestone above the conglomerate limestone on the Newburgh quadrangle has been recently (Holzwasser '26) designated the *Balmville limestone* after the town of Balmville. A series of rocks exposed at Rochedale, Dutchess county, has received the name of *Rochedale group* (Dwight '87). The fossils reported indicate that they are the equivalent of the Beekmantown, but these beds have never been mapped separately from the Wappinger limestone.

The fossils. Characteristic fossils of the Cambrian and Ozarkian formations in New York State are illustrated in figures 27 and 28. They are as follows:

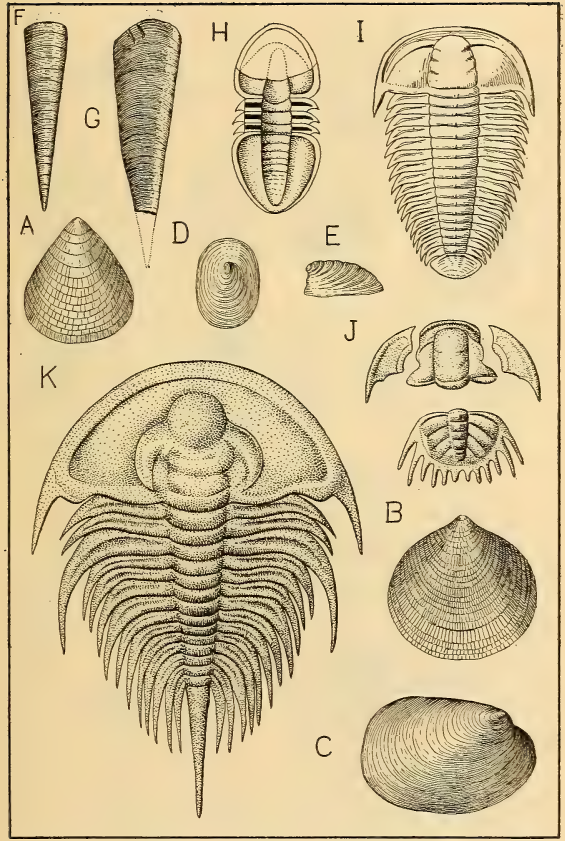


Figure 27 Lower and Middle Cambrian fossils. *G*, Middle Cambrian. (Brachiopods, *A, B;* pelecypod, *C;* gastropod, *D, E;* conularids, *F, G;* trilobites, *H-K*). *A Obolella gemma*, x6. *B O. crassa*, x3. *C Fordilla* (*Aristozoe ?*) *troyensis*, x2. *D, E Stenotheca rugosa*, x2. *F Hyolithes communis*, x2. *G H. americanus*, x2. *H Microdiscus speciosus*, x2. *I Atops trilineata*, x½. *J Olenoides fordi*, x2. *K Olenellus thompsoni*, x½.

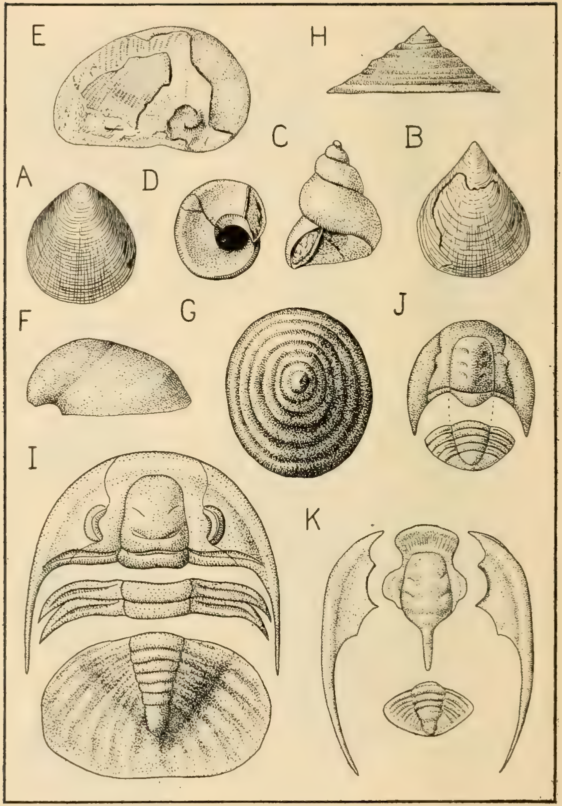


Figure 28 Lower Ozarkian fossils. (Brachiopods, *A, B;* gastropods, *C-H;* trilobites, *I-K*). *A, B Lingulepis acuminata,* x2. *C, D Matherella saratogensis,* x2. *E Pelagiella hoyti,* x6. *F Triblidium cornutiforme,* x5. *G, H Palaeacmæa typica,* x1. *I Tellerina hartti,* x½. *J Plethopeltis saratogensis,* x1. *K Saratogia calcifera,* x1.

Lower and Middle Cambrian Fossils

BRACHIOPODS

Obolella crassa (Georgian)
Obolella gemma (Georgian)

GASTROPODS

Stenotheca rugosa (Georgian)
(Probably a pteropod or heteropod)

CONULARIDS

Hyolithes americanus (Middle Cambrian)
Hyolithes communis (Georgian)

TRILOBITES

Atops trilineata (Georgian)
Mesonacis asaphoides (Georgian)
Microdiscus speciosus (Georgian)
Olenoides fordi (Georgian)
Olenellus thompsoni (Georgian)

PHYLLOPODS

Fordilla (Aristozoe?) troyensis (Georgian)

Lower Ozarkian Fossils[1]

BRACHIOPODS

Lingulepis acuminata (Potsdam, Theresa, Hoyt)

GASTROPODS

Matherella saratogensis (Hoyt)
Palaeacmea typica (Potsdam)
Pelagiella hoyti (Hoyt)
Triblidium cornutiforme(Hoyt)

TRILOBITES

Plethopeltis (Agraulos) saratogensis (Hoyt)
Tellerina (Dicellocephalus) hartti (Hoyt)
Saratogia (Lonchocephalus) calcifera (Hoyt)

[1] Most of the listed Ozarkian fossils (and others) occur also in the Lower Ozarkian formations in Wisconsin and Michigan.

Literature. For the general discussion of the Cambrian and Ozarkian, the student (as in the chapter on the Precambrian eras) is referred to the textbooks of geology by Chamberlin and Mac Clintock ('30), Chamberlin and Salisbury ('09, '30), Cleland ('16, '30), Coleman and Parks ('22), Grabau ('20), Schuchert ('24), Scott ('24), and to Schuchert and LeVene ('27). For climates, besides the textbooks, may be added Schuchert ('14). Books of a technical nature dealing with the Paleozoic in general are Schuchert ('10) and Ulrich ('11). Many references to Cambrian literature, but of a technical nature, will be found under Walcott in the Bibliography of North American Geology, published annually by the United States Geological Sur-

vey (among them Walcott '85, '86, '90, '91, '12, '15, '08-'22). The Cambrian section of northwestern Vermont is discussed in Keith ('23).

Among the bulletins of the New York State Museum are Miller ('24), in which will be found numerous references, Cushing ('05a) and Miller ('17). For the Cambrian, Dale ('04), Ruedemann ('30), Gordon ('11), Berkey and Rice ('21), Holzwasser ('26) may be consulted, and other references will be found in these bulletins. For the Ozarkian are suggested Cushing ('05b) Ulrich and Cushing ('10), Cushing and Ruedemann ('14) and Chadwick ('20). Then for classification of New York formations there is Hartnagel ('12).

Canadian and Ordovician Periods

The rocks of Ordovician age in Wales were classed by Sedgwick as a part of the Middle and the whole of the Upper Cambrian, but Murchison made the type of his Lower Silurian rocks of the same geological age in South Wales. The Silurian system was divided into two parts by Murchison (1835), which were called the Lower and Upper Silurian, a classification that is followed by some even to the present day. Some followed Sedgwick, others Murchison and it was not until after the proposal by Professor Lapworth (1879) of the name Ordovician for the Lower Silurian that geologists in general came to an agreement. The name was taken from the *Ordovices,* an ancient Celtic tribe which at the time of the Roman conquest occupied the territory now included in northeastern Wales and the adjoining parts of England. Great Britain, Sweden, Norway, Denmark and the United States have accepted this classification, but in other European coun-

tries the name Silurian is retained as defined by Murchison. In America the name Champlainian for this broad system is also used. This name, taken from Lake Champlain (New York-Vermont) where most of the formations now included under that term are well developed, was proposed in 1842 by the geologists of the New York State Survey.

Geology. As with the Cambrian so the Ordovician rocks of Wales are strongly folded and much broken, with numerous igneous intrusions and lava sheets. The most typical representation of the Ordovician system in Europe occurs in the Bohemian basin where the rocks are richly fossiliferous and have been very thoroughly studied. Nowhere in the world are the Ordovician rocks preserved in such completeness and with so little alteration as in North America, especially in the eastern section. Many of the formations of this series are very fossiliferous and the fossils are found beautifully preserved. The formations were first studied in greatest detail in New York State which is therefore regarded as the standard section and the current names of the formations are those used in New York. Other important localities in America are the province of Ontario in Canada, the Upper Mississippi valley region, the Cincinnati and Nashville domes and the Appalachian valley area. In the northern Appalachian region the rocks which consist more often of sandstones and shales have been intensely folded, as seen in the Upper Hudson valley and slate belt country of New York and Vermont, and are similar in appearance to the old rocks of Wales. In the Cordilleran region also, rocks of this system are found and have been traced into Arctic regions.

The name *Canadian* was first used as a group name (Dana '74) for a series of formations (Lower Ordovician) which were well-developed in northern New York and Canada, from which country the name was taken. The separation of this group from the Ordovician as a distinct system has recently been proposed (Ulrich '11); and the name of the group was retained for the system, which is set off from the Ozarkian below by a complete break and is also marked at the top by a complete break throughout North America.

The close of the Ozarkian and beginning of the Canadian is marked by a general withdrawal of water from present land areas. Nowhere has continuous deposition been found from the Ozarkian into the Canadian. The returning waters assumed a different arrangement, and the trangressions of the sea at least in two stages during this period were more extensive than the trangressions that occurred later in the Ordovician (Lowville and Trenton seas). The sea gradually occupied the country in the Acadian area of Canada, in eastern and central United States and in the Cordilleran area. There was pronounced submergence in Nevada and Utah. The period therefore was one of emergence with deposition over wide areas at certain stages, and it was also a period essentially of dolomite making. The aggregate thickness of Canadian deposits is somewhere around 7000 feet mostly limestones and dolomites. The greatest thickness in the east is found in the middle and southern Appalachian area; in central United States, in Oklahoma; in the west, in the Rocky Mountains region of Nevada and Utah. In New York the Beekmantown limestone of this age is replaced in the Hudson valley near Albany

by a series of shales and sands (Deepkill) of the same age, characterized by graptolites belonging to the Atlantic fauna and indicating a connection at that time with the Atlantic ocean. The Levis beds at Levis opposite Quebec are also such graptolite shales. The Canadian (Beekmantown) and the Lower Ordovician (Chazy) are represented by a great thickness of limestone in northern and western Newfoundland and in northwestern Scotland, and they have essentially the fauna found in those rocks in our Champlain valley showing that these areas belonged to the same marine province in these periods.

The *Ordovician system* is separated from the Canadian by a complete break throughout North America due to a withdrawal of the sea at the end of Canadian time. After its return, at several times during the course of the Ordovician period the retreat of the marine waters was so nearly complete that if any remained it could be only in certain of the now deeply covered basins. During this period and the preceding North America was little above sea level, and uplands occurred only along the margins of the continent. These periods, therefore, were characterized to a large extent by limestone building since the seas were receiving less sediments because of the low relief of the surrounding land. The transgressions of the sea during the Ordovician were extensive (Lowville and Trenton seas), but less extensive, certainly, than the Upper Ozarkian sea and probably also less widely spread than two of the Canadian stages (Ulrich). The down-warping of the eastern interior of the continent permitted the entrance of seas, not connected with the Atlantic ocean, to cover large areas

in eastern United States and the southern part of Canada. Many oscillations of land and water occurred during Middle Ordovician times. There was a great spreading of the continental seas early in the epoch (Mohawkian) which included a great inundation from the Arctic ocean. This Arctic inundation reached its greatest extent during Trenton time. The submergence of North America at this stage in the Ordovician was more extensive than at any other time except early Mohawkian (Lowville sea). Floodings from the Atlantic ocean in the Lower and early Middle Ordovician epoch were restricted to eastern North America (Alabama to Newfoundland only) and in the Cordilleran area there was a seaway from the Great Basin region to the Arctic ocean. At the close of the Middle Ordovician there was a vast but not complete withdrawal of the marine waters from the middle and northern areas of the continent. Some marine waters perhaps remained in the southern portion of the eastern interior and Appalachian areas in which a nearly complete, but now only partly accessible, record of marine deposition between the two epochs may occur. When the Middle Ordovician sea had nearly vanished a new invasion of the sea spread over the continent, from the Gulf of Mexico in Upper Ordovician time. This sea advanced northeastward along the western side of Appalachia, spreading northward into the Ottawa region, and westward into Indiana.

Ordovician deposits have a maximum thickness of several thousands of feet with a limestone value of about 8000 feet, that is, limestones plus the equivalence in limestone of the clastics which are more rapidly deposited. The greatest thickness of limestones

is in the southern Appalachian area. With the great retreat of the seas at the end of Canadian (Beekmantown) time the greater part of the continent became dry land which was gradually covered with sands that were moved about and built into dunes by the winds. These deposits seem to be confined to the Mississippi valley. Submergence during the Lower Ordovician (pre-Chazyan) permitted the sea to rework these sands into a basal bed. Such a basal sandstone (the St Peter sandstone, top member of Buffalo series) occurs at the surface or underground over nearly the whole area of the Upper Mississippi valley (Illinois, Iowa and Missouri, much of Wisconsin, Minnesota and Michigan, Indiana and smaller parts of other states) marking the horizon of the unconformity between the Ordovician and older formations (either Upper Ozarkian or, more generally, Upper Canadian) and always succeeded by early Mohawkian (usually beds of Lowville age). This is a pure quartz sandstone ranging in thickness up to 200 feet, with well-rounded grains assorted according to size. In the Lower Ordovician in several places (as in the Hudson valley in the vicinity of Albany) only deposits of muds and sands that contain characteristic graptolite faunas were laid down. As in the case of similar Beekmantown (Canadian) shales, the fossils of these Ordovician shales indicate a connection with the Atlantic. Elsewhere limestones commonly characterize the earlier deposits of the Ordovician. The Middle Ordovician was also a time of limestone-making on a wide scale. During this epoch (Mohawkian) the dominant rocks were thin-bedded limestones and shales. The Middle Ordovician limestones and especially the Tren-

ton are found in New Brunswick, New York, Michigan, southeastern Canada, and over the upper and middle parts of the Mississippi valley. The Kentucky-Tennessee area shows unconformities indicating alternating emergence or elevation and submergence. During the last epoch (Upper Ordovician), while the thin-bedded limestones are common, more muds (shales) are found with them, and these sediments occurred in increasing amounts toward the close of the Upper Ordovician with a prevalence of sandstones. The Upper Ordovician of the east consists largely of a thick mass of shales and minor thicknesses of sandstone, representing clastic sediments spread widely over the sea floor. The increase in deposits of muds and sands of this epoch is due probably to elevation of the land, allowing the streams to carry increased loads, and to accompanying shallowness of the sea. These shales and slates extend from the St Lawrence to Tennessee along the Appalachian area and are thickest toward the east. In the Hudson valley of New York State, these immensely thick beds of shales and slates were once regarded as a distinct series and placed at the top of the Ordovician. They are now known to be a separate facies and represent the Canadian and the Ordovician through the Trenton. The Upper Ordovician strata of east central and western United States differ markedly from those of the east in consisting mostly of limestones with some shales, and are richly fossiliferous. These beds exposed around Cincinnati have given the name Cincinnatian to the series. Bryozoans and brachiopods play an important part in these strata, often forming entire beds of limestone. The Upper Ordovician of the west is much more restricted and in

many places lies unconformably upon the Middle Ordovician, indicating a period of uplift and erosion. Older Ordovician rocks fringe the great northern Precambrian area in the west and are even found in the islands of the Arctic sea.

The oscillatory movements, that is, the submergences and emergences, throughout the Ordovician were slow and gentle, so that the Ordovician period may be regarded as a period of quiet, with epicontinental seas gradually increasing in size to their greatest expansion in the middle epoch when the greater part of the southeastern quarter of the continent was submerged. At the end of the period the lands were again drained leaving the outlines of the continent much as they are today. The close of the Ordovician is marked by a time of widespread disturbance and mountain making, known as the *Taconic Emergence, Disturbance,* or *Deformation,* traces of which are found in North America and Europe, especially along the Atlantic slope of each continent. The great masses of sediments that had accumulated in the northern part of the Appalachian trough were subjected to lateral pressure and folded. The Taconic range along the line between New York and New England was upheaved at this time and has given its name to the period of deformation. Its rocks were greatly compressed, folded and metamorphosed and sedimentary beds from the Cambrian to and including the Ordovician were involved. Evidences of this disturbance have been found as far south as Alabama. In Nova Scotia and New Brunswick Silurian beds are found resting upon the upturned edges of Ordovician strata but the upheaval does not appear to have extended to the northern part of the Gulf of St Lawrence. In the Hudson valley of New York and in parts

of Pennsylvania the strongly folded and eroded Ordovician beds are overlain in some places by Upper Silurian strata, in other places by Middle or Upper Silurian or even Lower Devonian beds and everywhere the unconformity between the two systems, marking the old erosion surface or plane, is well shown although later disturbance has taken place. Metamorphism of the sediments involved in this disturbance was brought about by the heat generated by the folding and by the intrusion of igneous material in many parts of New England and in eastern Canada. The limestones of Vermont were changed into marbles and the mudrocks or shales of Vermont and eastern New York became roofing slates. Sandstones were altered into quartzites.

The interior sea apparently was entirely drained, since there are no deposits transitional to the Silurian found in that area; but it was not long before the sea had again encroached upon the Mississippi valley. Large areas, however, in the west and northwest remained land for long periods. The first deformation movements in the middle states started in the Middle Ordovician (Trenton time) in low folds which, though later submerged, were arched up again by lateral compression at the close of the period during the time of the Taconic Disturbance. Among these were the domes of the Cincinnati anticline which were not only elevated but greatly enlarged at the close of the period. This fold has its longer axis in a northeast-southwest direction and extends from the southern border of Tennessee to southwestern Ohio. Its presence and character is particularly notable at the surface by doming of the outcropping rock formations at the northern and southern ends of the anticline, the northern

part of the structure being known as the Cincinnati dome, the southern part as the Nashville dome.

Petroleum and natural gas have been found in all of the fossiliferous rocks from the Ordovician through the Tertiary. Some of the richest pools have been found in the Ordovician and Devonian. The Ordovician (Mohawkian) limestones of Ohio have yielded large quantities of oil and gas. Among other economic products of the period are the slates of the Appalachian region, especially those of Vermont and Pennsylvania (Upper Ordovician). Because of the wide distribution of the limestones there are important marble, limestone and cement industries. Lead deposits occur in the Galena formation (post-Trenton age and probably later) of the middle west. The deposits of zinc in Wisconsin are in pre-Trenton (Mohawkian) rocks.

Life. So far as fossils are concerned in the separation of these early Paleozoic systems it may be said that true graptolites, such ostracods as *Leperditia* and true Orthidae are first seen in the Upper Canadian; whereas such other brachiopods as *Orthis, Dalmanella, Platystrophia* and *Camarotoechia* and such trilobites as *Illaenus, Isotelus, Calymene* etc., certain groups of corals, true bryozoans, pelecypods, true ostracods and typical crinoids are unknown beneath the base of the Ordovician.

In the *Canadian* rocks of the St Lawrence province the fossils are chiefly *graptolites* belonging to the Atlantic realm and similar or identical with species of Great Britain, Norway and Sweden. These are found in the dark shales characteristic of that area and also in similar shales of like age farther south in Vermont, New York and Pennsylvania (Deepkill). Among the characteristic graptolite genera of these shales are *Tetragraptus, Phyl-*

lograptus, Dichograptus and *Goniograptus.* The Schaghticoke shales typically exposed near Schaghticoke, Rensselaer county and representing the lowest Canadian in New York are characterized by the graptolite *Dictyonema flabelliforme.* Graptolites are very important as zone markers, since they have a wide interoceanic distribution. The Appalachian province of this period is characterized by a series of heavily bedded dolomites and limestones, particularly in the southern Appalachian area, which thin out westward. There are also more than 2000 feet of these dolomites and magnesian limestones in western Newfoundland. These dolomites are often marked near the base by the lime-secreting *alga* Cryptozoön, but besides these algae are poor in fossils, particularly the lower beds. In favorable places heavy-shelled *gastropods* and both straight and coiled *cephalopods* are found. The flat-coiled gastropod genus *Ophileta* is found in the lower beds and in the upper beds the loosely coiled forms, *Eccyliopterus* and *Eccyliomphalus,* the trilobite *Asaphus* and cephalopods such as *Cameroceras, Tarphyceras, Schroederoceras* and *Protocycloceras.*

The *Ordovician* shows a notable advance in its life and by the close of this time not only were all of the great types of marine invertebrates represented but also many of their most important subdivisions. More than a thousand Cambrian species are known for North America, but several times this number are known from the Ordovician, a very great diversity of marine invertebrates coming in with the widespread Middle Ordovician transgression of the continental seas. Several groups reached their culmination in the Ordovician and became much less important in succeeding periods. Such groups were

the graptolites, the cystoids among the echinoderms, and the straight-shelled cephalopods.

Plants above the grade of seaweeds have not been found in the Ordovician. *Receptaculites* and *Solenopora,* forms very characteristic of this period and usually placed with the sponges or corals, have recently been shown to be plants. The former built hollow, dish or vase-shaped skeletons, sometimes a foot in diameter, with an inner and outer layer connected by pillars, and is easily recognized even in fragments. Certain beds of the Ordovician (Upper Chazy) are largely composed of them. The *Solenopora* forms pebblelike masses consisting of very small tubes arranged in radial manner from a point on their base. The fact that *Foraminifera* and *Radiolaria* are found in a few regions in great numbers indicates that they were abundant in the Ordovician seas. *Sponges* are represented by forms with silicious and calcareous skeletons and, though rare in New York formations, are very common in the Lower Ordovician limestones of the southern Appalachian area. *Graptolites* here as in the Canadian are important horizon markers, but there is a completely different series. Among the characteristic genera are *Nematograptus, Climacograptus, Dicellograptus, Dicranograptus* and *Diplograptus.* The *hydrocorallines,* allied to the corals and represented by *Stromatopora*-like forms which were abundant as reef builders in the Silurian and Devonian, are found also in the Ordovician. *Corals* were still rare but represented by several types, among them the simple cup-corals, as *Streptelasma.* The common forms were those living in colonies, as the large-tubed *Columnaria* and peculiar forms (*Tetradium*) with quadrangular tubes. The echinoderms were represented by all groups, *cystoids, blastoids, crinoids, starfishes, brittle*

stars and *sea urchins*, but the blastoids and sea urchins are extremely rare, the blastoids being represented by only one species and that somewhat doubtful. Representatives of the last three groups are rare but very characteristic when found. *Cystoids*, as pointed out above, reached their culmination in this period. Among the characteristic and common genera are *Malocystis*, *Pleurocystis* and *Agelacrinus*. The earliest *blastoids* (*Blastoidocrinus*) appear in the Lower Ordovician (Chazy), but they became important much later (Carboniferous). These primitive forms show notable cystoidian characters. The *crinoids* were locally so abundant in the Ordovician that in certain places whole layers of rocks are composed of their dissociated plates. Even heads are abundant. Among the common genera are *Glyptocrinus*, *Heterocrinus*, *Dendrocrinus* etc. While crinoids were numerous in the Ordovician, they did not attain their greatest development until later. *Bryozoans* were so numerous that they were more important as limestone makers than the brachiopods. They were abundant not only in numbers but in species, probably numbering more than a thousand, and are valuable as index fossils because of their great number, wide distribution and limited range in time. *Brachiopods*, too, are found very abundantly in Ordovician beds and are also important as horizon markers. About 500 forms are known for North America. The thin-shelled hingeless types so characteristic of earlier periods are less in evidence, and have been replaced by the hinged forms, though the highest types have not yet made their appearance in numbers. Among the genera found are *Lingula*, *Schizocrania*, *Rafinesquina* and the reversed form *Strophomena*, *Dalmanella*, *Dinorthis*, *Platystrophia*, *Zygospira*, *Rhynchotrema*, *Camarotoechia*

and *Plectambonites. Plectambonites sericeus* is very common both in the middle and upper series of rocks, even to such an extent that thick layers of limestone are almost entirely composed of it. The *Platystrophia* group is practically confined to the Ordovician. Among *gastropods* forms with spirally coiled shells have increased in number but both high and low-spired forms abound. Among the important genera are *Eotomaria, Hormotoma, Trochonema, Raphistoma, Bellerophon* types, and *Maclurea*. The last named, a flat-spired, left-handedly coiled form, is particularly characteristic of the period, though it already occurs in the late stages of the Canadian. Although not uncommon, neither the gastropods nor the bivalve mollusks (pelecypods or lamellibranchs) approach anywhere near the relative importance they have in modern times. Pelecypods are still comparatively rare as fossils, and are more abundant in the sandstones and shales of the period than in the limestones. Characteristic genera are found in the peculiar *Ambonychia* and *Byssonychia* which possesses a large wing on one side of the beak. Mussellike forms, such as *Modiolopsis,* are also found, but similar forms occur also in younger (later) beds.

The *cephalopods* were probably the most powerful animals of the Ordovician and showed great diversity. They all had shells of the type of the Pearly Nautilus of the present day and these shells were straight (*Orthoceras*), curved (*Cycloceras*) or tightly coiled (*Trocholites*). The straight-shelled forms were most characteristic and reached their culmination in this period. Other genera are *Oncoceras,* the straight form with rapidly tapering cone, *Gonioceras,* very characteristic of the Middle Ordovician, and the coiled *Eurystomites* also represented in the Upper Canadian. Ordovician *trilobites* fall far short

in numbers of species from those now known to us from the Cambrian and even the Ozarkian, despite more limited exposures and less favorable rocks for preservation, is already crowding the Ordovician in numbers of species. The Canadian has many, yet fewer than any of the other Eopaleozoic systems (Ulrich). More than 300 forms are known from the Ordovician, and they belong for the most part to intermediate types. Disregarding the giants, the Ordovician trilobites differ little in average size from those of other systems. Few of the lowest types have survived and few of the highest types have been introduced. Among the most striking forms is *Isotelus* in which the head and tail are similar and each constitutes about one-third the length. It is as large as any trilobite known, reaching 24 inches in length and ten inches or more in width. *Illaenus* is as abundant and new for the period as any. Other characteristic genera are *Calymene,* which is often found coiled in a ball, the spiny *Ceraurus, Bumastus* and *Trinucleus. Trinucleus* (*Cryptolithus*), distinguished by a large head with three bulging lobes and a flat, ornamented rim prolonged into a lateral spine on each side, is one of the most characteristic forms. *Ostracods,* small, bivalve crustaceans, were also very abundant during all or most portions of the period. One of the common genera is *Leperditia.* Another group is represented in the Ordovician, but not abundantly. These are the *eurypterids* which had a remarkable development in the Silurian and Devonian. The existence of vertebrates in the Ordovician is doubtful. The fish remains found in the basal sandstone (Harding) of the Rocky Mountain region (Colorado and Wyoming) are of Silurian age. The Harding sandstone is much younger than the St

Peter (Lower Ordovician) and Ulrich places it at the base of the Richmond, hence at the base of the Silurian.

Climate. So far as known at present the climate was uniformly mild and equable, that is, warm temperate, throughout the northern hemisphere in both Canadian and Ordovician times, as indicated by the vast accumulations of limestones and dolomites, the reef corals of the Middle Ordovician and the fossils found in Arctic lands.

New York formations. The Beekmantown (Canadian) submergence in New York State in general begins with deposition of the Tribes Hill limestone which overlies the Little Falls dolomite nearly everywhere in the Mohawk valley. As far west as Middleville and Newport it is absent showing that the Little Falls sea here lapped farther north on the Adirondack oldland. The Tribes Hill also does not extend as far north as Saratoga, and the exact equivalent of the formation has not been found in the Champlain valley. The Tribes Hill submergence had a different pattern than the Little Falls sea, occupying more limited embayments on the south and west side of the Adirondack area, while the latter covered the southern and eastern flanks. The depression in the west lasted only a short time. The uplift following tilted the land to the east giving rise to a long continued submergence in the Champlain valley. The remaining divisions of the Beekmantown limestone are confined to this trough with its prolongations north and south and the Ogdensburg area on the northwest side of the Adirondacks. A narrow body of water connected with the North Atlantic, called the Levis channel and believed to be distinct from the other seaway, extended from New-

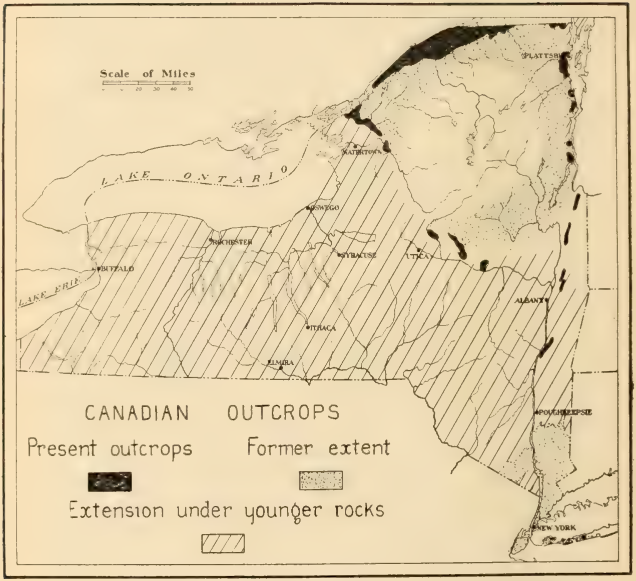


Figure 29 Canadian outcrops. The probable former extent of the seas of this period and the extension of the formations under those of younger age are shown.

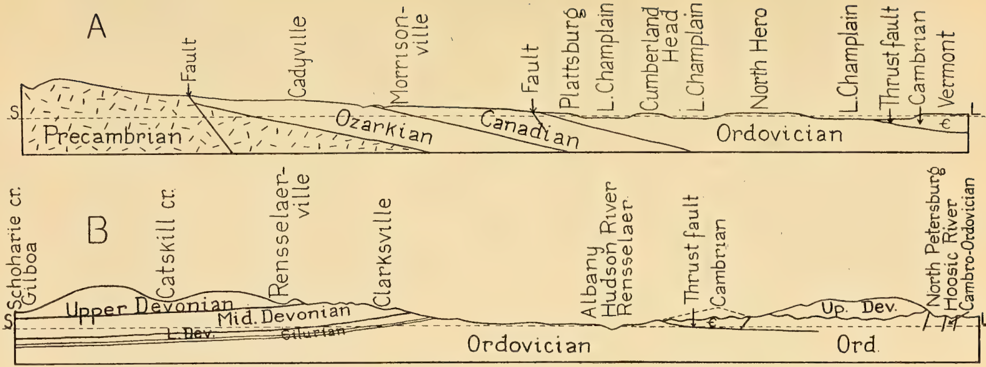


Figure 30 *A* East-west section across Lake Champlain in the vicinity of Plattsburg. Horizontal scale: approx. ½ inch = 3 miles. Vertical scale: approx. ½ inch = 5280 feet. *B* East-west section across the Hudson river at Albany, from the Schoharie valley (Gilboa) to the Hoosick valley (North Petersburg). Horizontal scale: approx. ½ inch = 6 miles. Vertical scale: approx. ½ inch = 5280 feet.

foundland into New York State, entering from the northeast. In this trough thick formations of graptolite shales were deposited. The Upper Canadian beds are found in the Ottawa valley and in the south they have been found at intervals in southeastern New York (Wappinger terrane), New Jersey and Pennsylvania, in the last-named state having a thickness of 2000 to about 4000 feet. The strata of Beekmantown age in New York have an aggregate thickness of 1500 to 2000 feet. At the end of Beekmantown time uplift and withdrawal of the sea produced the unconformity between the Beekmantown (Canadian) and the Chazy (Lower Ordovician). (Figures 29, 30.)

There is no positive evidence that the entire Adirondack area was ever submerged during Ordovician times, so the central Adirondacks must have persisted as an island in the Ordovician sea. There were a number of oscillations through the period bringing the land around the island now above sea level, again below, but it is not necessary to enter into that here. Except for this island formed by the Adirondacks and the alternating conditions in its vicinity, New York State was entirely or almost entirely submerged practically throughout Ordovician time after the Chazyan (Lower Ordovician). Some even believe that the Middle Ordovician (Trenton) sea submerged the entire Adirondack area. During this time the prominent land masses were the land mass of Appalachia to the east and another to the north in the Hudson Bay region of Canada. Limestones characterize the earlier Ordovician deposits in the state not because the water had great depth or was far away, but because the neighboring lands were of low relief and there was little clastic material carried by the streams. During the latter part of the period the lands were higher, erosion

was more active forming more muds and sands to be washed into the sea, so the later deposits were shales and sandstones. In southeastern New York the so-called *"Hudson River"* shales and sandstones overlie the Wappinger terrane and in the northern part of the State Canajoharie, Utica and Lorraine shales and sandstones overlie the Chazy, Black River and Trenton limestones. The Ordovician strata in New York have an aggregate thickness of about 5000 feet, mostly deposited in a shallow sea, even the limestones. The complete thickness is not found in any one place, nor are all the formations present in unbroken succession, since oscillations of land and sea have in some areas and then in others caused interruptions in sedimentation.

The Ordovician formations of New York (figures 32–34) were first studied by Ebenezer Emmons, Geologist of the Second New York District and he grouped them together as the Champlain System from the extensive exposures bordering the lake, but his Champlain system also included Canadian and probably also some Ozarkian. In Vermont and in the Taconic range of mountains forming the New York-Massachusetts boundary line the rocks are very strongly folded and metamorphosed and very difficult to distinguish. Most American geologists of Emmons' time referred this whole series to the Ordovician. Emmons regarded them as belonging to an older system which he called the Taconic; and he was in part correct, though it is now known that besides the older rocks there are infolded and faulted strata of Canadian and Ordovician age. The discussion that arose over the age of these folded and metamorphosed rocks has been termed the *"Taconic Controversy."* The classification of the New York formations follows, dashes marking the

absence of beds in the three sections. No exposures have been found west of the central part of the state.

ORDOVICIAN SYSTEM

Central	*East Central*	*Eastern*	
Cincinnatian	**Cincinnatian**	**Cincinnatian**	
(Upper)	(Upper)	(Upper)	
Oswego ss.	——	——	
Lorraine beds			
Pulaski sh.	——	——	
Frankfort sh.	Frankfort sh.	Indian Ladder beds	
Utica sh.	Utica sh.	——	
Mohawkian	**Mohawkian**	**Mohawkian**	
(Middle)	(Middle)	(Middle)	
Trenton beds	Trenton beds	Trenton beds	
Dolgeville sh.	Schenectady sh.	Schenectady sh.	
Trenton l.s.	Canajoharie sh.	Canajoharie sh.	
		(Snake Hill sh. of same age farther east)	
——	Glens Falls l.s.	Glens Falls l.s.	Normanskill shales (*incl. at top Rysedorph cgl.*)
Black River beds	Black River beds	Black River beds	
——	Amsterdam l.s.	Amsterdam l.s.	
Watertown l.s.	——	——	
Leray l.s.	Leray l.s.	Leray l.s.	
Lowville l.s.	Lowville l.s.	Lowville l.s.	
Chazyan	**Chazyan**	**Chazyan**	
(Lower)	(Lower)	(Lower)	
Chazy beds	——	Chazy beds	
——	——	Valcour l.s.	
Pamelia l.s.	——	——	
——	——	Crown Point l.s.	
——	——	Day Point l.s.	

CANADIAN SYSTEM

Central	*East Central*	*Eastern*	
Middle and Upper	**Middle and Upper**	**Middle and Upper**	Deepkill shales
Beekmantown beds	Beekmantown beds	Beekmantown beds	
Ogdensburg dol.	——	Beekmantown l.s.	
		(*incl. div. C-E and B in part*)	
Lower	**Lower**	**Lower**	
Tribes Hill l.s.	Tribes Hill l.s.	Tribes Hill l.s.	
——	——	Schaghticoke sh.	
		(*farther east*)	

The *Schaghticoke shales* (Ruedemann '03) are typically exposed along the Hoosick river, at and in the vicinity of Schaghticoke, Rensselaer county, and constitute the lowest beds of the Canadian in New York State which do not occur farther west (figure 31). Lithologically they are similar to the Deepkill beds (p. 272), and are thin, equally bedded, alternating greenish and black shales, with intercalated thin barren limestone bands.

Figure 31 Lower Canadian rocks. Schaghticoke shales with the graptolite *Dictyonema flabelliforme* at Schaghticoke, Rensselaer county. (Photograph by G. Van Ingen)

These beds were formerly included in the "Hudson River" group. Two graptolite zones are recognized (1 and 2), the *Dictyonema flabelliforme* fauna and the *Staurograptus dichotomus* fauna. The fauna characterized by *Dictyonema flabelliforme* also occurs in Canada and in Europe, where it is considered by some as belonging to early Ordovician, by others as marking the closing stages of the Cambrian (= Ozarkian). The total thickness of the Schaghticoke shales is not known. Only about 50 feet are exposed but the thickness is probably considerably more.

The *Tribes Hill limestone* constitutes the basal Canadian in the Mohawk valley, resting nearly everywhere on the Little Falls dolomite but its exact equivalent has not been found in the Champlain valley or in the vicinity of Saratoga Springs. This formation is also present in the Ogdensburg and Thousand Islands region. It is a sandy limestone. Weathering gives a peculiar gothic fretwork appearance which in the earlier days (Vanuxem '42) gave a basis for the name *Fucoidal layers.* This was part of Vanuxem's "Calciferous" group of the Mohawk valley. The limestone is quite fossiliferous and its Canadian age is unquestionably indicated by the fossils. *Asaphus* and three or four other trilobites not known in Ozarkian formations are found, the gastropod *Eccyliomphalus multiseptarius,* the brachiopod *Dalmanella? wemplei* and the *Ribeirias* (crustaceans: branchiopods). The Tribes Hill limestone varies in thickness up to about 40 feet.

All the divisions of the *Beekmantown limestone* (Clarke and Schuchert '99) have not yet been named. The formation received its name from Beekmantown in Clinton county where the typical development and fauna

is found. It has a maximum thickness in the Champlain region of about 1500 feet (Shoreham, Vt.). These beds were formerly included in the "Calciferous" group of the Mohawk valley, part of which (division A and the basal portion of division B, marked at the top by an unconformity) is now placed with the Little Falls dolomite (Ozarkian). The "Calciferous" of the Champlain valley was studied by Brainerd and Seely ('90) and divided into five divisions (A, B, C, D, E). The Beekmantown, as restricted, comprises the upper part of B through E. Thus division C, which has a thickness of 350 feet and consists of thick beds of magnesian limestones alternating with thinner beds of calcareous sandstone is considered typical middle Beekmantown. The upper part of the division D and the whole of E have been given the name *Cassin formation* (Cushing '05) from the Fort Cassin exposure. Except for a calcareous alga, Cryptozoön, fossils are rare in the lower beds. The middle division is rather abundantly fossiliferous. The flatly coiled gastropod genus *Lecanospira* is particularly characteristic and is found at a corresponding horizon in Quebec, northwest Scotland, through the Appalachian valley to central Alabama, in Missouri, Oklahoma, Texas and in the Cordilleran region far northwest toward the Arctic (Ulrich). In the upper beds are found cephalopods of the *Endoceras* type and other forms, and gastropod genera as *Ophileta* and *Eccyliomphalus* etc. In the Ogdensburg area the representation of the Beekmantown above the Tribes Hill has been called the *Ogdensburg dolomite* (Cushing '16). There are 120 feet of this limestone representing only the upper beds of the Champlain area (Middle and Upper Canadian).

The *Bald Mountain limestone* (Ruedemann '14) named from its occurrence in the fine quarries at the foot of Bald mountain in Washington county contains a Beekman town fauna and it is suggested (Ruedemann '14, '30) because of the southern Appalachian and Missouri fossils found (*Eccyliopterus planidorsalis, E. planibasalis,* Ulrich MSS) that this limestone continues through the eastern slate belt and may form a part of the Wappinger terrane in southeastern New York. This formation is of Upper Canadian age and has a thickness up to 100 feet.

The *Deepkill shales* (Ruedemann '02) are for the most part equivalent in age to the Beekmantown limestones but the uppermost graptolite zone carries a Chazy fauna (Ruedemann). They were deposited in the Levis trough farther east. These shales, formerly included in the "Hudson River" group, as were the Schaghticoke shales occur in the Hudson valley in the vicinity of Albany and were named from the typical exposure in Grant Hollow, Rensselaer county, along the Deepkill, a tributary of the Hudson river from the east. The graptolite shales of the Canadian and Ordovician in New York have been divided into 20 graptolite zones, and three of these into well-characterized subzones. The Deepkill shales carry five of these zones (3 to 7) with seven subzones. From oldest to youngest they are zones of *Clonograptus flexilis, Phyllograptus typus, Didymograptus* (*D. nitidus, D. extensus*), *Didymograptus bifidus* (with *Goniograptus geometricus, D. similis*), *Diplograptus dentatus* (with *Climacograptus pungens, Phyllograptus angustifolius, Trigonograptus ensiformis*). The Deepkill shales show an alternation of limestones with shaly intercalations, sandy shales and grits, thin-bedded shales, grits and limestones, and limestones with greenish silicious shales and black

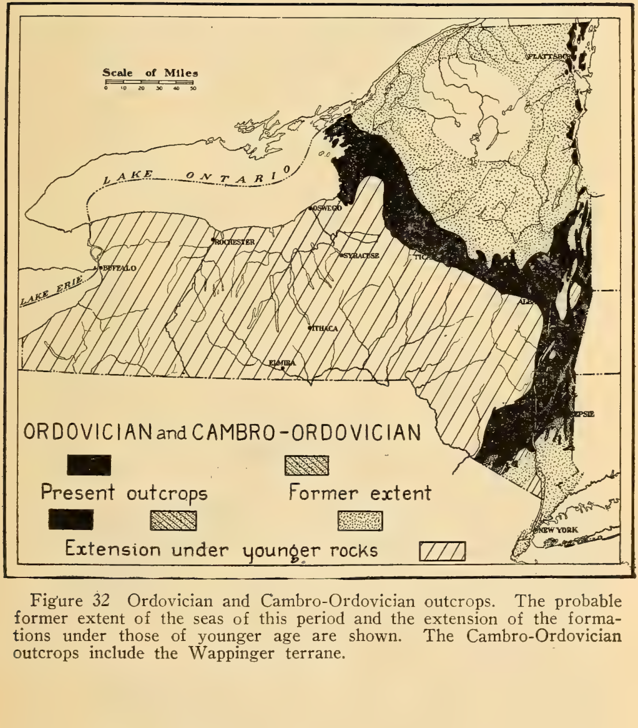


Figure 32 Ordovician and Cambro-Ordovician outcrops. The probable former extent of the seas of this period and the extension of the formations under those of younger age are shown. The Cambro-Ordovician outcrops include the Wappinger terrane.

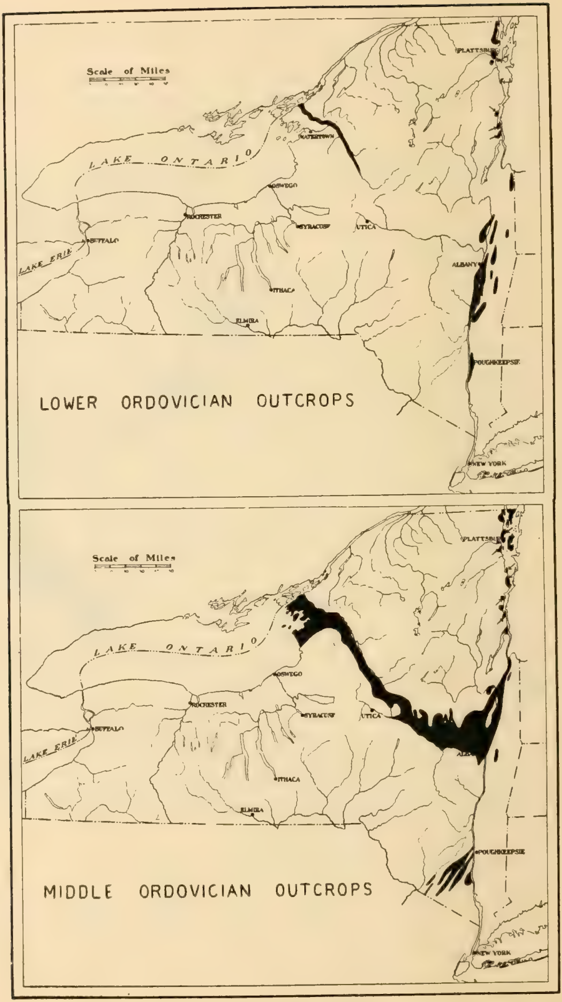


Figure 33 Lower (Chazyan) and Middle Ordovician outcrops

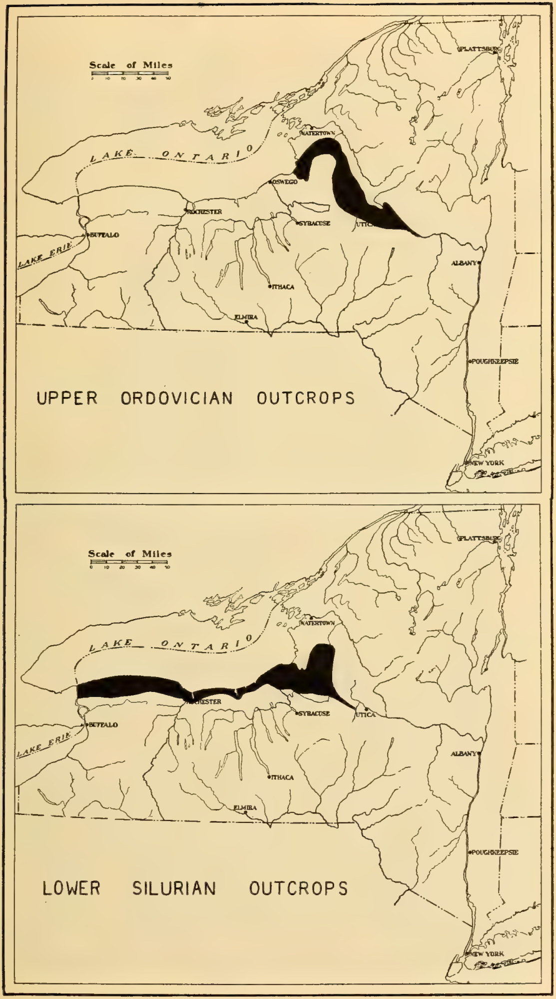


Figure 34 Upper Ordovician and Lower Silurian outcrops

graptolite shale. The deep black, soft graptolite-bearing mud shales are always inclosed in the greenish gray, very hard and thin-bedded silicious layers. The calcareous bands are very characteristic of the shales. The Deepkill shales have a maximum thickness between 200 and 300 feet.

The Beekmantown fauna of the limestones of the Wappinger terrane in southeastern New York has already been discussed (p. 243).

The *Chazy beds* represent the Lower Ordovician of New York and were named (Emmons '42) from Chazy village in Clinton county where they are well exposed. These limestones occur at the present day only on the eastern border of the Adirondack region, their present distribution giving little idea of the extent of the sea in which they were deposited. The formation is thickest in the latitude of southern Clinton county, thinning rapidly southward until it has disappeared entirely at the lower (southern) end of Lake Champlain. It also thins northward and changes considerably in character. Brainerd and Seely made three divisions of these limestones which they called A, B, C and to which Cushing ('05) gave the names *Day Point limestone* (A), *Crown Point limestone* (B), *Valcour limestone* (C). Each division is characterized by different fossils. In the thickest section on Valcour island (figure 35) about 900 feet are exposed. The Lower Chazy (A) has a thickness of 338 feet and besides the characteristic brachiopod, *Orthis costalis,* has species of the cephalopods *Orthoceras, Cameroceras* and *Plectoceras;* the cystoid *Paleocystites;* the trilobites, *Illaenus* and *Harpes* etc. The Middle Chazy (B) has a total thickness of 350 feet and besides the characteristic left-handedly coiled *Maclurea magna* has species

Figure 35 Lower Ordovician rocks. Cliff of Chazy limestone, Valcour island, Lake Champlain. (Photograph by G. H. Hudson)

of the brachiopods *Orthis, Leptaena* and *Strophomena;* the gastropods *Raphistoma, Scalites* and *Bucania;* the cephalopods *Orthoceras, Cameroceras* and a *Gonioceras;* the trilobites *Harpes, Illaenus* etc.; the calcareous alga, *Solenopora compacta* etc. The Upper Chazy (C) has a total thickness of 202 feet and is characterized by the small, plicated rhynchonelloid brachiopod *Camaratoechia plena,* having besides in its basal part species of large straight and coiled cephalopods, *Orthoceras, Cameroceras, Oncoceras* and *Tarphyceras* and the trilobite *Glaphurus.* Throughout most of the Champlain valley the limestones show quite a pure character and are commonly fine-grained. The so-called black marble of Isle La Motte in Lake Champlain is Chazy.

The *Pamelia limestone* (Cushing '08) in central New York is of an age intermediate between the Middle and Upper Chazy of the Champlain valley (= Depauville waterlime, Emmons '40). It received its name from the town of Pamelia in Jefferson county. The formation consists essentially of limestone, though the bulk of it is not pure limestone, with a thin basal sandstone followed by shale (10–20 feet). These basal beds are weak and seldom exposed. The maximum thickness of the formation is 125 to 150 feet and it is considered as the overlapping edge of the Chazy (Upper Stones River formation) from the southwest, not previously recognized in New York State. The dove limestone beds in the upper part of the formation have mud-cracked surfaces which with the ostracod fauna and the presence of waterlimes indicate shallow water and basin conditions. The limestones of the lower portion, however, are fossiliferous and indicate that there was a period of open water pre-

ceding this which permitted the entrance of a marine fauna.

The *Normanskill shales* (Ruedemann '01) are in part equivalent in age to the Upper Chazy limestones but were deposited in the Levis trough farther east. They were named from the typical exposure at Kenwood, along the Normanskill, a tributary of the Hudson river just south of Albany (figure 36). They, too, are graptolite-bearing shales formerly included in the old "Hudson River" group. Two graptolite zones (8 and 9) are represented in the Normanskill shales, that of *Nematograptus gracilis* and that of *Corynoides gracilis* which is considered of Black River age (Ruedemann). The formation contains a large and cosmopolitan graptolite fauna. There are probably 2000 feet of Normanskill shales which vary considerably lithologically, for the most part, however, consisting of dark gray to black argillaceous shales. Red and green shales also occur, and the formation is particularly characterized by heavy beds of white-weathering chert (2–10 feet) and grit (2–30 feet). Above this last zone in the Mohawk valley is a graptolite zone (10 *Cryptograptus tricornis insectiformis*) of Snake Hill (Trenton) age which was formerly described as the *Magog shales* and is now in process of revision (Ruedemann). The *Rysedorph conglomerate* (Ruedemann '01) occurs in Rysedorph hill (locally called Pinnacle or Sugar Loaf hill) two miles southeast of Rensselaer (across the river from Albany), and overlies the Normanskill. It is a fine collecting ground for fossils. The youngest pebbles are of Trenton age, but faunas represented by the pebbles range from Lower Cambrian to Trenton. Seven kinds of pebbles have been found furnishing an amazingly rich and strange fauna, with Atlantic elements hitherto known

Figure 36 Lower Ordovician rocks. The Normanskill graptolite shales, Kenwood, Albany county. (Photograph by E. J. Stein)

only from Europe. The Rysedorph conglomerate has a wide distribution within the Normanskill shale belt in the capital district. At the north it has been found at the base of Bald mountain and at the south at Schodack Landing along the Hudson river. At the type locality the bed is two and one-half feet thick, but in other sections it shows varying thicknesses up to 50 feet (Moordener kill, near Castleton). The *Burden conglomerate* (Grabau '03) is found near Becraft mountain and other places in the vicinity of Hudson within the Normanskill shales. No fossils have been found. It is thought that this may be identical with the Rysedorph conglomerate.

The *Black River beds* (Vanuxem '42) include the Lowville, Leray, Watertown and Amsterdam limestones. They are chiefly confined to the Mohawk and Black River valleys but also occur farther east in the Upper Hudson and Champlain valleys. The Black River series consists of thin-bedded, often somewhat bituminous limestones with a maximum thickness of about 150 feet and with many fossils. The *Lowville limestone* (Schuchert and Clarke '99) has its best development in the region of the lower Black river where it has a maximum thickness of 60 feet. The basal bed is conglomerate and of variable thickness, but typically it consists of thick and thin-bedded, fine-grained dove limestone which weathers a characteristic ashen gray color. This is the "Birdseye" formation of Eaton ('24) who first described it from the Mohawk valley. The name was derived from the fact that the limestone contains numerous more or less vertical worm tubes, *Phytopsis tubulosum,* which are filled with calcite producing the birdseyes in cross-section. The present name is from the exposures in the town of Lowville, Lewis county. This formation is also characterized

by a profusion of the horizontally spreading, tabulate coral *Tetradium cellulosum* and related species. Intercalations of a subcrystalline dark to black limestone or of oölitic or shaly, whitish-weathering limestone contain a larger fauna than the dove limestone, carrying pelecypods, gastropods, cephalopods, ostracods and trilobites. Other characteristic forms than the two mentioned above are the cephalopods *Orthoceras recticameratum* and *O. multicameratum*, the trilobite *Bathyurus extans* and the ostracod *Leperditia fabulites.* The uppermost layers (maximum 15 to 20 feet) of the Lowville beds are cherty beds, found to be separated from the typical beds (Lowville limestone) by an unconformity, and this portion has received the name *Leray limestone* (Ruedemann '10) from the exposures at Lerayville, Jefferson county. The term is applicable to the corresponding beds in the Champlain valley. The *Watertown limestone* (Ruedemann '10) is the name used for the "seven-foot tier" or Black River limestone of Hall ('47) and was derived from typical exposures at Watertown, Jefferson county. In natural exposures or in places where the quarry face is weathered, the Watertown and Leray formations are readily distinguished from the Lowville formation below by their breaking up into small cubic blocks the size of a fist. The thick-bedded, blocky-weathering beds contrast well with the evenly and thinner-bedded Lowville. The Watertown limestone is very hard, thick-bedded, dark bluish gray or black (about nine feet, including black knotty limestone above). The characteristic cephalopods for which it is renowned are *Gonioceras anceps, Hormoceras* (*Actinoceras*) *tenuifilum, Eurystomites* (*Plectoceras?*) *undatus.* Heads of the coral *Columnaria,* with numerous prismatic tubes, are common. These fossils already ap-

pear in the cherty beds below, but the characteristic Lowville fossils have disappeared. The Lowville-Leray formations are but slightly represented in the Champlain valley; there are intermediate beds representing the Lowville-Leray hiatus or unconformity of the northwest; the Watertown limestone is missing due to widespread uplift at the close of the Leray. Subsidence followed in the east with the accumulation of the *Amsterdam limestone* which is entirely absent in the west. The name was given (Cushing '11) from the exposures at Amsterdam, Montgomery county. It is the "Mohawk" limestone of Vanuxem. This is a dark limestone like the Watertown with a maximum thickness of 60 feet and carries about the same fauna.

The *Trenton beds* comprise limestones and shales and sandstones. The *Glens Falls limestone* (Ruedemann '12), named from the exposures at Glens Falls, Warren county, has been determined to be of very early (basal) Trenton age. It is well developed in the Mohawk and Upper Hudson valleys where it has a thickness of 17–40 feet. This limestone is missing below the typical Trenton limestone at Trenton Falls. Collections in this limestone show a fauna including numerous brachiopods, abundant seaweeds, some trilobites and cystoids, as *Pleurocystites*. The *Trenton limestone* (Conrad, Vanuxem '38) received its name from the type section at Trenton Falls on West Canada creek (figure 37). It is extensively developed both to the west and east of the Adirondacks, but on the south the formation is interrupted by numerous faults. There is a rapid decrease in thickness of the Trenton limestone eastward in the Mohawk valley and a rapid increase of the shale in that direction. With the exception of a bed of compact, barren limestone at the base the Trenton

Figure 37 Middle Ordovician rocks. The Trenton limestone, Trenton Falls, Utica, Oneida county.

is composed of thin beds of limestone alternating with calcareous shaly layers of equal thickness which are very fossiliferous. The Trenton limestone has a maximum thickness in its western exposures of about 300 feet and in northeastern New York of at least 350 feet. While much thicker than the Black River (Watertown) limestone below, the Trenton is a much less resistant formation. Characteristic fossils are the bryozoans *Prasopora simulatrix* and *Pachydictya acuta,* the brachiopods *Dalmanella rogata* (*testudinaria,* authors) and *Plectambonites sericeus,* and the trilobites *Isotelus gigas, Calymene senaria* and *Cryptolithus tessellatus* (*Trinucleus concentricus*). A hundred feet of passage beds, shales, between the Trenton and Utica, previously described as the "Trenton-Utica passage beds" were given the name of *Dolgeville shales* (Cushing '09, in Miller) from their typical development along East Canada creek below Dolgeville in Herkimer county. They are considered "as a shaly eastern representative of the Upper Trenton limestone of the type section." Similar passage beds in the Lake Champlain region north and east of Plattsburg have been mapped as the *Cumberland Head shales* (Cushing '05). North of Trenton Falls younger beds of Trenton habit overlap from the north on the Trenton limestone (in strict sense). These beds are now known to be of lower Utica age and separated from the Trenton as the *Cobourg limestone* (Raymond '21).

The *Canajoharie shale* (Ruedemann '12) received its name from the typical outcrop at Canajoharie in Montgomery county. This formation has a maximum thickness of more than 1200 feet and represents the lower part of the black shale above the Trenton limestone in the lower Mohawk valley, previously regarded as of Utica

age. These soft, black shales are characterized by their uniform, carbonaceous, fine-grained character. They form a broad belt in the lower and middle Mohawk valley. Toward the west these beds pass into the middle and lower Trenton limestone; in the east they are overlain by the Schenectady beds. They pass up into the Champlain valley and are found at Ticonderoga and especially on the Vermont side. Five graptolite zones (11 to 15) are represented in these shales, namely those of *Mesograptus mohawkensis, Diplograptus amplexicaulis, Glossograptus quadrimucronatus cornutus, Lasiograptus eucharis, Climacograptus spinifer.* The fauna of the Canajoharie is a very characteristic one, consisting besides graptolites, of small individuals of brachiopods, mollusks, trilobites and ostracods, suggesting unfavorable conditions of life as do also the black, carbonaceous, pyrite-bearing shales.

The *Snake Hill beds* (Ruedemann '12) contemporaneous with the Canajoharie are shales, grits and sandstones deposited above the Normanskill shales in the eastern Levis trough and, as with the other shales, formerly classed as part of the old "Hudson River" group. They received their name from the very fossiliferous exposures at Snake Hill on the east side of Saratoga lake. Large and distinctive faunas have also been found around Albany, Green Island, Mechanicville, Cohoes etc. These beds are lithologically similar to the Normanskill shales but are without the strong development of grits and white-weathering chert beds; argillaceous shales prevail. The black, carbonaceous, graptolite-bearing bands occur more frequently than in the Normanskill formation, but the graptolite fauna, comparatively, is much impoverished. On the other hand small gastropods, brachiopods

and trilobites, of which only traces have been observed in the Normanskill, are frequently seen in the Snake Hill shales. The formation has an enormous thickness, 3000 feet being considered a minimum measurement (Ruedemann). In the Hudson valley it forms the broad belt of shales between the Normanskill shales and Wappinger limestone at the bank of the river to the Skunnemunk mountains and has a computed thickness in Orange county of 1500 to 2000 feet which is regarded as a minimum figure considering the width of the belt. The fauna of these shales is a large one. It contains some of the characteristic Canajoharie forms and also a fauna that came in from the north. There are a number of strange fossils that have not been found elsewhere. Included in the fauna are the graptolites *Corynoides gracilis, Diplograptus* (*Glyptograptus*) *amplexicaulis, Climacograptus typicalis, Lasiograptus eucharis* and *Glossograptus;* the cystoid *Edrioaster saratogensis;* crinoids as *Glyptocrinus cf decadactylus* (joints) and *Heterocrinus gracilis;* bryozoans as *Prasopora* and *Pachydictya;* brachiopods as *Dalmanella rogata* (*testudinaria*), *Plectambonites sericeus, Rafinesquina alternata* and *Zygospira recurvirostra;* pelecypods as *Cuneamya acutifrons, Clionychia undata, Orthodesma? subcarinatum;* gastropods as *Lophospira bicincta, Tetranota bidorsata, Cyrtolites* cf *retrorsus;* the conularid *Conularia trentonensis;* cephalopods as *Spyroceras bilineatum* and *Endoceras proteiforme;* and trilobites as *Eoharpes ottawaënsis, Cryptolithus tessellatus, Triarthrus becki, Calymene senaria* and ***Isotelus gigas.***

The *Schenectady beds* (Ruedemann '12) receive their name from typical exposures in the vicinity of Schenectady. They overlie the Canajoharie shale and are now known to be of upper Trenton age, though previously

they were included in the "Hudson River" group and considered of Lorraine or Frankfort age. This formation has a thickness of at least 2000 feet, and consists of grits and sandstones with interbedded black and gray argillaceous shales which form a uniformly alternating series throughout the whole formation. It occurs in the southwest corner of the Saratoga quadrangle and from there extends in a broad belt (six to eight miles wide in the capital district) between Schenectady and the Helderberg escarpment reaching into the Schoharie valley (at Schoharie village). It is believed to owe its thickness to deposition in a sinking basin in front of the rising Green mountains in the east (Ruedemann). In Albany county the Schenectady beds are overlain by the Indian Ladder beds; farther to the southwest in Schoharie county they are overlain by the Silurian (Brayman shales). The most characteristic fossil of the Schenectady beds is the seaweed *Sphenophycus latifolius.* Included in its fauna are the graptolites *Dictyonema multiramosum, Diplograptus vespertinus, Climacograptus spinifer, C. typicalis,* and *Lasiograptus* (*Thysanograptus*) *eucharis;* the brittle star *Taeniaster schohariae;* brachiopods as *Leptobolus insignis, Dalmanella rogata, Plectorthis plicatula;* the pelecypod *Saffordia ulrichi;* gastropods as *Cyrtolites* cf *ornatus;* the conularid *Conularia trentonensis* var. *multicosta;* the cephalopods *Spyroceras bilineatum* and *Trocholites ammonius;* the trilobites *Triarthrus becki, Isotelus gigas* and *Cryptolithus tessellatus* Eurypterids deserve special mention and include the genera *Eurypterus* (*E. pristinus*), *Eusarcus* (*E. triangulatus*), *Dolichopterus* (*D. frankfortensis*), *Hughmilleria* (*H. magna*), *Pterygotus* (*P. nasutus*) and *Stylonurus?* (*S. limbatus*). This fauna contains elements of both the Utica and Trenton faunas and a fauna of its own

(*Sphenophycus latifolius, Dictyonema multiramosum, Taeniaster schohariae, Saffordia ulrichi* and the eurypterids in particular).

The Black River or lower Trenton fauna in the Wappinger terrane of southeastern New York has already been discussed (p. 243).

The Utica-Lorraine formations constitute the Upper or Cincinnatian epoch of the Ordovician in New York State. The group has its best development in Ohio and Indiana, whence the name has its origin. The *Utica shale* (Emmons, Vanuxem '42) derives its name from an exposure in the creek east of the city of Utica in Oneida county. This is a widespread formation, being especially well-developed in the Mohawk valley and toward the St Lawrence valley in the northwest. No exposures have been found in eastern New York. The Utica shales are black and gray argillaceous shales, sometimes with interbedded gray sandstones, which in the type section attain a thickness of nearly 800 feet. The Utica shale proper contains three graptolite zones and in its broader conception (including the *Atwater Creek* and *Deer River shales* that come in from the north) five graptolite zones (16–20), namely, *Climacograptus typicalis, Dicranograptus nicholsoni, Climacograptus pygmaeus, Climacograptus typicalis posterus* and *Glossograptus quadrimucronatus typus.* Besides the graptolites, characteristic forms of this fauna are the brachiopod *Leptobolus insignis,* the cephalopods *Trocholites ammonius* and *Geisonoceras tenuistriatum* and the trilobites *Isotelus gigas, Cryptolithus tessellatus* and *Triarthrus eatoni* (= *becki, authors*).

The *Lorraine beds* include the Frankfort and Pulaski shales. The name was taken from the village of Lorraine in Jefferson county (Emmons '42) and was originally used for all the beds above the supposed Utica in north-

western New York, although the Frankfort was not recognized as a distinct member. The *Frankfort shale* (Vanuxem '40) was named from the typical exposure along Moyer creek southwest of Frankfort, Herkimer county, where it is overlain by the Oneida conglomerate (Silurian). It extends from the Mohawk north and west into Lewis and Jefferson counties. In eastern New York the Indian Ladder beds of the same age occur. The Frankfort beds attain their greatest development in the Utica basin where they have a thickness of about 500 feet. They thin out northwestward and westward pass under younger formations. These beds consist of black and gray argillaceous shales, prevailingly more gray than the Utica. Its fauna, as found in the shales at Frankfort, connects the formation with the Utica instead of the typical Lorraine (Pulaski) beds. The fauna includes Utica graptolites as *Climacograptus pygmaeus, C. typicalis, Glossograptus quadrimucronatus;* brachiopods as *Leptobolus insignis, Schizocrania filosa;* the worm *Serpulites crassimarginalis;* the cephalopod *Geisonoceras tenuistriatum* mut. *frankfortense;* and the trilobite *Triarthrus eatoni.* The appendages of the famous *Triarthrus eatoni* described as *becki* by Beecher came from these beds. Other Frankfort forms not occurring in the Utica are the graptolites *Mastigograptus laevis* and *Inocaulis arborescens,* the brachiopod *Lingula progne* and the trilobites *Cryptolithus bellulus* and *Proëtus beecheri.* The fossils characteristic of the Frankfort shales, are the brachiopods *Camarotoechia? humilis* and *Leptobolus insignis latus,* the cephalopod *Geisonoceras tenuistriatum frankfortense* and the trilobites *Cryptolithus bellulus* and *Isotelus stegops.*

The *Pulaski shales* (Vanuxem '40) received their name from the village of Pulaski in Oswego county, where the

shale is exposed along the Salmon river. These beds are made up of predominant gray shales alternating with sandstone beds which are often calcareous, rusty brown-weathering and sometimes a foot or more thick. There are also thin limestone bands. These and the calcareous sandstone bands are highly fossiliferous. In the uppermost Pulaski the gray noncalcareous sandstone beds begin to predominate. The Pulaski shales are found in north central New York, from Rome northward, and have a thickness of about 400 feet. Some of the characteristic fossils of these beds are the brachiopod *Zygospira* (*?*) *erratica;* the cephalopod *Orthoceras lamellosum;* the pelecypods *Modiodesma modiolare, Orthodesma nasutum, Pterinea demissa, Byssonychia radiata, Clidophorus planulatus;* and the trilobites *Isotelus maximus pulaskiensis, Cryptolithus lorrainensis* and *C. bellulus.* A large brachiopod, *Rafinesquina alternata nasuta* and also *R. mucronata* occur in the uppermost beds. The Pulaski shales are a mud facies and therefore characterized by a large number of pelecypods or lamellibranchs. Such a facies is also termed a "lamellibranch" facies.

The *Oswego sandstone* was described by Vanuxem ('42) as the "Gray sandstone of Oneida," and was earlier designated the "Salmon River sandstone" because it occurs at Salmon river capping the Pulaski shale. The fauna of the last Lorraine zone has been traced (Ulrich and Foerste) into undoubted Oswego sandstone in the cliff at Salmon River falls, establishing the fact that there is no lithologic break between the Pulaski and Oswego. The Oswego sandstone thus is considered as the closing phase of the Ordovician rather than one introducing the Silurian. The sandstone occurs in Oswego, Oneida, Lewis and Jefferson counties and then passes westward

out of the State as a concealed formation. It has a maximum thickness of about 100 feet.

The *Indian Ladder beds* (Ruedemann '12) are typically exposed in the Black creek ravine, Indian Ladder, Albany county, hence the name (figure 52). These beds extend from there, rapidly thinning below the Helderberg escarpment, to the north and to the south. They disappear a short distance south of the village of New Salem on the south, and on the north only a few feet are found after crossing the Altamont-Knox state road. The Indian Ladder beds have a thickness of over 400 feet of which the lower hundred feet are dark gray to black argillaceous shales with two heavy sandstone beds. Above this are alternating gray shales and thin, yellow, rusty-looking, calcareous sandstone bands, which are very characteristic. The uppermost portion becomes quite sandy, consisting in the upper hundred feet or so of prevailing heavy sandstone beds with interbedded dark arenaceous or argillaceous shales and sometimes a limestone band. This formation is on the whole quite barren. Graptolites, as *Dictyonema arbusculum* and *Dicranograptus nicholsoni* have been found in the shales, but the calcareous sandstone bands have yielded the larger fauna, in which are included the bryozoan *Hallopora onealli,* the brachiopods *Dalmanella multisecta, Rafinesquina ulrichi* and *Plectambonites centricarinatus,* the ostracod *Ceratopsis chambersi* and the trilobites *Cryptolithus bellulus* and *Odontopleura crosota.* The fauna of the Indian Ladder beds is not represented anywhere else in eastern New York; the beds are of Cincinnatian (Frankfort) age. This, together with the restricted horizontal (east and west) distribution, suggests that the Indian Ladder beds were deposited in an inde-

pendent arm of the sea extending from the south northward in one of the long troughs of the Appalachian region.

Two characteristic sections showing the formations of the Canadian and Ordovician systems may be studied: the Lake Champlain section and the section west of the Adirondacks. In the Lake Champlain section, in going from west to east, one passes from the crystallines of the Adirondacks across the Potsdam sandstone, Theresa passage beds, Hoyt limestone and Little Falls dolomite of the Ozarkian to the Beekmantown limestone (Canadian) which forms the western shore of the lake at many points and has a maximum thickness of 1500 feet. Then come the Black River-Trenton series of limestones of about 300 feet, mostly Trenton (since there is a small representation of Lowville and Leray followed by the Amsterdam with no Watertown present). Following these beds is a series of black, bituminous shales, the Canajoharie shales (formerly called Utica) which end the section in Vermont, since it is cut off at the east by a fault. To the west of the Adirondacks the Black river follows for some distance the contact line between the crystallines and sedimentaries. In the banks here is found the Lowville limestone (Black River series) resting upon the crystallines. Underneath these beds but not appearing at the surface, because overlapped by the Lowville, are the older formations which appear at the surface farther to the northeast, namely, the Potsdam, a small representation of the Beekmantown and the Chazy (Pamelia limestone). The Chazy does not occur in its typical form outside the Champlain valley. Succeeding the Lowville is the Black River (Watertown) lime-

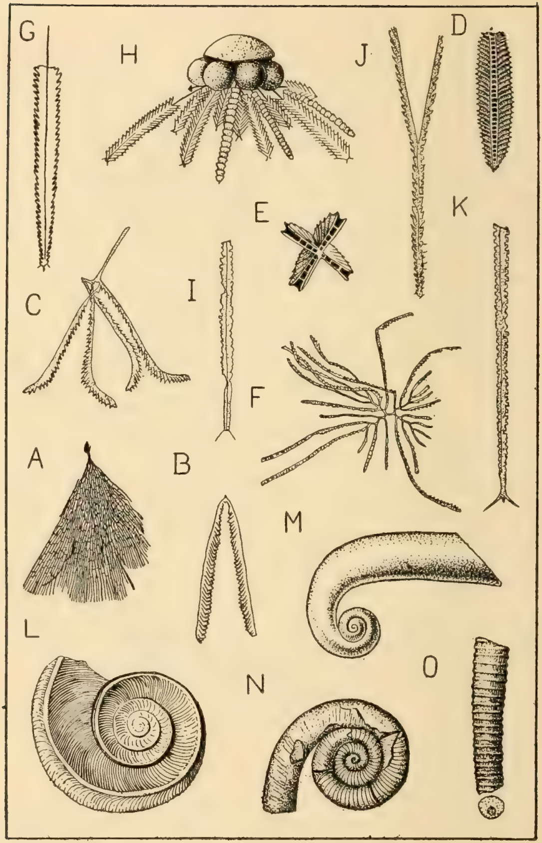


Figure 38 Canadian and Ordovician fossils. Canadian, *A-F, L-M*. (Graptolites, *A-K;* gastropods, *L, M;* cephalopods, *N, O*). *A Dictyonema flabelliforme*, x½. *B Didymograptus bifidus*, x½. *C Tetragraptus fructicosus*, x½. *D Phyllograptus angustifolius*. *E Phyllograptus typus*, restored cross section. *F Goniograptus thureaui*, x½. *G Glossograptus quadrimucronatus* (= *Diplograptus pristis*), x½. *H* Colony of the same restored. *I Climacograptus spinifer*. *J Dicranograptus spinifer*. *K Climacograptus bicornis*. *L Ophileta complanata*, x¾. *M Eccyliomphalus lithuiformis*, x1/3. *N Shroederoceras catoni*, x1/3. *O Protocycloceras lamarcki*, x½.

stone with its characteristic cephalopods, followed by the Trenton limestone, typically exposed at Trenton Falls. The limestones are succeeded by the Upper Ordovician (Cincinnatian) shales: the black Utica shales with their characteristic graptolite zones, the sandy shales of the Frankfort and the mud or "lamellibranch" facies of the Pulaski formation, the last two formations constituting the Lorraine beds which are capped by the Oswego sandstone.

We have seen in New York State in the Middle Ordovician a lateral change in character of sediments from east to west. The limestones of Trenton time in the west are replaced by shales, mudrocks of nearshore origin, in the east, the Canajoharie shales. As the limestone deposition continued in the clear water of the west the muds from Appalachia spread farther and farther westward (Utica shale) covering limestone beds previously deposited. The muds and limestone beds are everywhere conformable and indeed pass into one another (progressive overlap). The mud phase was succeeded by a sandy phase (Schenectady beds), the sandy beds beginning at a higher level in the west (Lorraine beds) just as do the black muds, that is, the first mud beds of the east are older than the first mud beds farther west, and the same is true of the sandy beds. The black muds of both the east and west (Canajoharie, Utica) are characterized by graptolites. In the Hudson valley (Levis trough) the entire Canadian and Ordovician is represented by shales and sandstones (the old "Hudson River group") with characteristic graptolite faunas.

The fossils. Characteristic fossils of the Canadian and Ordovician systems are illustrated in figures 38 to 41. They are as follows:

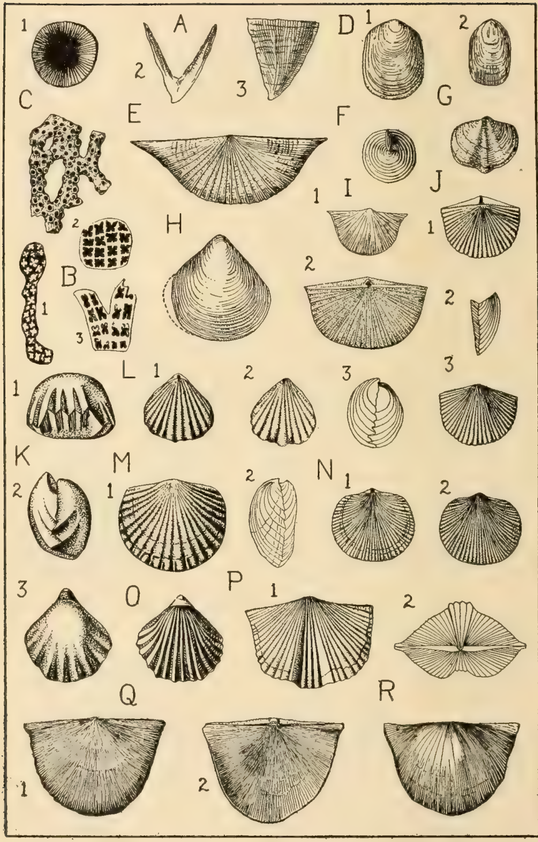


Figure 39 Ordovician fossils. (Corals, *A, B;* bryozoan, *C;* brachiopods, *D-R.* *A* 1, 2, 3 *Streptelasma profundum.* *B Tetradium cellulosum,* cross sections: 1, x1; 2 & 3, x2. *C Phylloporina reticulata,* x7. *D* 1, 2 *Lingula rectilateralis,* x½. *E Leptaena incrassata,* x3/2. *F Orbiculoidea tenuistriata,* x2. *G Zygospira concentrica.* *H Glossina belli.* *I* 1, 2 *Plectambonites sericeus,* x3/2. *J* 1, 2, 3 *Orthis tricenaria,* x¾. *K* 1, 2, 3 *Camarella varians,* x3/2. *L* 1, 2, 3 *Rhyncotrema inequivalvis,* x¾. *M* 1, 2 *Dinorthis pectinella,* x¾. *N* 1, 2 *Dalmanella rogata,* x¾. *O Camarotoechia plena,* x¾. *P* 1, 2 *Platystrophia lynx,* x¾. *Q* 1, 2 *Rafinesquina alternata,* x½. *R Strophomena incurvata,* x½.

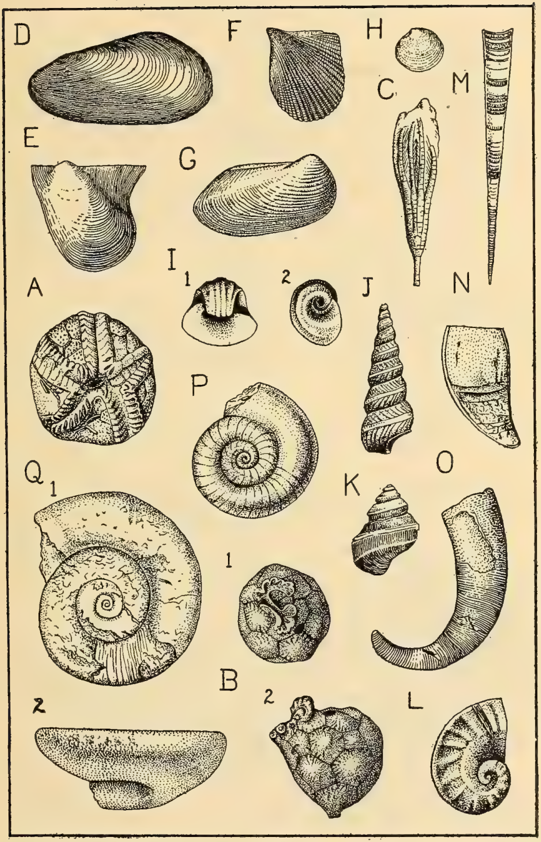


Figure 40 Ordovician fossils. (Cystoids, *A, B;* crinoid, *C;* pelecypods, *D-H;* gastropods, *I-L;* cephalopods, *M-Q*). *A Edrioaster saratogensis,* x2½. *B* 1, 2 *Malocystites emmonsi,* x2. *C Ectenocrinus canadensis,* x½. *D Modiodesma modiolare,* x½. *E Pterinea demissa,* x½. *F Byssonychia radiata,* x½. *G Cuneamya scapha. H Ctenodonta pectunculoides. I* 1, 2 *Tetranota bidorsata. J Hormotoma trentonensis,* x¾. *K Lophospira bicincta. L Cyrtolites ornatus,* x¾. *M Orthoceras multicameratum,* x¼. *N Oncoceras pristinum,* x¾. *O Cyrtoceras filosum,* x½. *P Trocholites ammonius,* x½. *Q* 1, 2 *Maclurea magna,* x⅓.

Canadian Fossils

GRAPTOLITES

Dictyonema flabelliforme (Schaghticoke)

Didymograptus bifidus (Deepkill)
Goniograptus thureaui (Deepkill)
Phyllograptus angustifolius (Deepkill)
Phyllograptus typus (Deepkill)
Tetragraptus fructicosus (Deepkill)

GASTROPODS

Eccyliomphalus lithuiformis (Up. Beekmantown)
Ophileta complanata (Beekmantown l.s.)

CEPHALOPODS

Protocycloceras lamarcki (Beekmantown l.s.)
Schroederoceras eatoni (Beekmantown l.s.)

(Many other highly characteristic fossils of Canadian age as *Lecanosp ra compacta* occur in the New York formations and are listed under the descriptions of the formations.)

Ordovician Fossils

GRAPTOLITES

Climacograptus bicornis (Normanskill)
Climacograptus spinifer (Snake Hill)
Dicranograptus spinifer (Normanskill)
Glossograptus quadrimucronatus (Snake Hill, Utica)
(=*Diplograptus pristis*)

CORALS

Streptelasma profundum (Black River)
Tetradium cellulosum (Black River)

BRYOZOANS

Phylloporina reticulata (Black River, Trenton)

BRACHIOPODS

Camarella varians (Chazy)
Camarotoechia plena (Chazy)
Dalmanella rogata (Chazy-Lorraine)
Dinorthis pectinella (Trenton)
Glossina belli (Chazy)
Lingula rectilateralis (Utica-Lorraine)
Leptaena incrassata (Chazy)
Orbiculoidea tenuistriata (Frankfort)
Orthis tricenaria (Trenton)
Platystrophia lynx (Trenton)
Plectambonites sericeus (Trenton-Lorraine)
Rafinesquina alternata (Trenton-Lorraine)
Rhynchotrema inequivalvis (Trenton)
Strophomena incurvata (Trenton)
Zygospira concentrica (Lorraine)

PELECYPODS

Byssonychia radiata (Lorraine)
Ctenodonta pectunculoides (Lorraine)
Cuneamya scapha cf mut. brevior (Lorraine)
Modiodesma modiolare (Lorraine)
Pterinea demissa (Lorraine)

GASTROPODS

Cyrtolites ornatus (Pulaski)
Hormotoma trentonensis (Trenton)
Lophospira bicincta (Trenton)
Maclurea magna (Chazy)
Tetranota bidorsata (Black River, Trenton)

CEPHALOPODS

Cyrtoceras filosum (Trenton)
Oncoceras pristinum (Chazy)
Orthoceras multicameratum (Lowville)
Trocholites ammonius (Trenton, Utica)

CYSTOIDS, CRINOIDS

Ectenocrinus canadensis (Trenton)
Edrioaster saratogensis (Snake Hill)
Malocystites emmonsi (Chazy)

TRILOBITES

Bathyurus extans (Lowville-Black River)
Bumastus trentonensis (Trenton)
Calymene senaria (Trenton)
Ceraurus pleurexanthemus (Lowville-Lorraine)
Cryptolithus tessellatus(Trenton-Lorraine)
Eoharpes ottawaënsis (Chazy)
Isotelus gigas (Trenton, Utica)
Proëtus beecheri (Frankfort)
Thaleops arctura (Chazy)
Triarthrus eatoni (becki) (Utica, Lorraine)

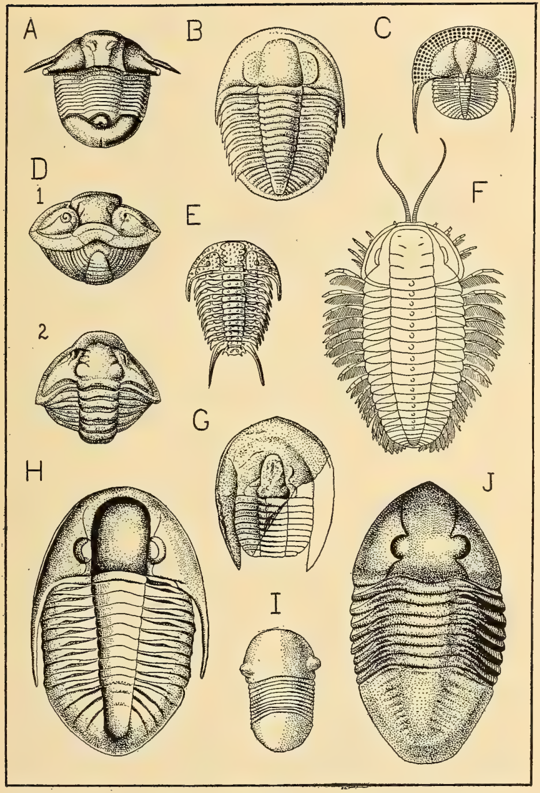


Figure 41 Ordovician trilobites. *A Thaleops arctura. B Proëtus beecheri*, x4. *C Cryptolithus tessellatus. D* 1, 2 *Calymene senaria. E Ceraurus pleurexanthemus*, x½. *F Triarthrus eatoni* (= *becki*). *G Eoharpes ottawaënsis*, x¾. *H Bathyurus extans. I Bumastus trentonensis*, x⅜. *J Isotelus gigas*, x½.

Literature. For the general discussion of these two systems the textbooks referred to under the preceding chapter on the Cambrian and Ozarkian may be used. To these references are added Bassler ('19), Grabau ('09), Schuchert ('10, '14) and Ulrich ('11).

Among the publications having reference to the New York formations the following are suggested: Brainerd and Seely ('90, '91, '96), Chadwick ('20), Clark ('19), Clarke ('99), Cushing ('05a, '08, '11), Cushing, Fairchild, Ruedemann and Smythe ('10), Foerste ('14), Hartnagel ('12), Holzwasser ('26), Miller ('09, '17, '24, with many references), Prosser and Cummings ('97), Raymond ('14), Ruedemann ('01a, b, '02, '03, '05, '06, '08, '10 (in Cushing etc., Bul. 145), '12, '19, '25, '30), Ulrich and Cushing ('10), Ulrich and Schuchert ('01).

Silurian Period

The name Silurian was given by Sir Roderick Murchison (1835) to a system of rocks occurring beneath the Old Red Sandstone series (Devonian) and previously unknown. He studied them on the borderland between England and southern Wales where they were least disturbed, and therefore gave to the system a name derived from the Silures, a warlike tribe that occupied this territory in the days of the Romans. "*The Silurian System*" appeared in 1838. Murchison then divided the system into an upper and lower division, the latter essentially of the age of Sedgwick's Upper Cambrian of North Wales for which Lapworth subsequently proposed the now generally accepted term Ordovician system. At the same time Lapworth also advocated restriction of the name Silurian to the

rocks comprised in Murchison's Upper Silurian, an arrangement now generally adopted by British and American geologists. It is of interest to note that the old New York term, Ontario division, as defined 1842–43, comprised almost exactly the same range of formations now referred to the Silurian system.

Geology. North America has as full a representation of the rocks of the Silurian system as occurs in Great Britain, and, as with the Ordovican and Devonian, the classification used in New York is the standard for America.

At the end of the Ordovician there was a withdrawal of the sea at the time of the mainly continental deposition of the Oswego sandstone. Then came a return of the sea (Richmond or Medinan) with a flooding from the Arctic ocean, as well as from the Middle and South Atlantic and Pacific. It was during this flood, when a large portion of the continent was submerged, that a river delta of red sandstones was deposited in the Appalachian trough and extended from near the southern extremity of Virginia through Maryland and Pennsylvania into New York where it appears as the red sandy shales of the Queenston formation. It is the erosion interval below the Richmond (Medinan) series, together with the Silurian types found in the fauna, that has led to the inclusion of the Richmond beds in the Lower Silurian (Ulrich). Some authors include all formations up to the Clinton beds (lower Middle Silurian) in the Ordovician, others make the division at the top of the Richmond. The break at the base of the Richmond is very marked over the greater part of the interior from the upper Mississippi valley west to the Rocky mountains and north

and south of this. The Richmond covers a greater proportion of the continent than any subsequent series of Silurian deposits. At the close of the Lower Silurian there was a great but not complete emergence followed by another great but oscillating submergence, that of the Middle Silurian (Niagaran) epoch. As in the preceding period (Ordovician) the highlands were along the borders of the continent and the interior basin was little above sea level. The Cincinnati dome was of no significance as a topographic feature until after Lower Silurian time when distinct marine basins were developed on both the east and west sides. The second flooding of this interior low area was somewhat inferior in aggregate extent to the one that took place in Lower Silurian (Richmond) and at this time approximately 20 per cent of the continent was under water. These floods were chiefly from the Arctic ocean, but smaller seaways spread northward from the Gulf of Mexico and in the west a seaway extended from California through Idaho to Canada. Little is known of the Cordilleran sea. Small seaways connected with the North Atlantic in the St Lawrence and Acadian areas, and there were times when there was a connection between the St Lawrence waters and the Appalachian trough. Epicontinental seas were again restricted in the Upper Silurian. Salinan time in northeastern North America is characterized by shifting lagoons and an arid climate. Along the northern part of the northeastern area of the interior sea salt lagoons were separated off and in these was deposited a series of red marls and shales interstratified with gypsum and rock salt. Following these came a freshening of the Salina lagoons and the deposition of

a waterlime containing a remarkable assemblage of fossils, the eurypterids. The interior sea throughout Salina age had been growing more shallow and finally became land and remained so for a time. The Silurian waters persisted in the Appalachian geosyncline (and elsewhere) and there were deposited the limestones of the closing period of the Upper Silurian (Cayugan) epoch, the Cobleskill, Rondout and Manlius.

The Silurian was largely a period of limestone building except in eastern United States which is characterized, particularly in the lower part, by conglomerates, sandstones and shales derived from Appalachia to the east and carried by streams given added impetus and carrying power by the uplift at the close of the Ordovician. These sandstones increase in thickness going east until they assume the character of great sand deltas (Tuscarora of Pennsylvania; Shawangunk of New York). The thickest accumulations are found in east central Pennsylvania where a maximum thickness of several thousand feet occurs. The lower part of these deposits is almost devoid of limestones and the upper part, constituting the Upper Silurian, consists of shales gradually becoming more and more calcareous. Both in Lower and Middle Silurian the Appalachian trough was plentifully supplied with sands and muds, and the sand deltas show no fossils except the worm trail *Arthrophycus*, showing that the trough was not occupied by normal sea water. Fossils occur in the higher mud deposits when submergence permitted free entrance of the sea to this part of the trough. In the interior sea the waters were warm and pure. Pure and magnesian limestones are found almost entirely, particularly in the Niagaran, due to the abun-

dant growth of corals and *Stromatoporas* which formed the reefs or reeflike accumulations, so characteristic of the Niagaran (Middle Silurian), which are best exemplified in Wisconsin and the Manitoulin Islands and also found in Michigan, Ohio and Indiana. Except in maritime eastern Canada, the thickest deposits of Silurian (mainly Middle Silurian) limestones occur in west central Tennessee. The dolomitic Niagara series in northeast Wisconsin and northern Michigan comes next. Between the limestone area of the interior and the region of sands and muds in the east was a transition zone in which sometimes sandstones and shales were deposited, then again limestones. The limestone deposits of the interior region belong largely to the Middle Silurian. Nowhere is there a thickness over 1000 feet, and usually it is much less, considerably under 500 feet.

At the base of the Middle Silurian (Niagaran) series is one of the most widespread iron ore deposits known. It was accumulated during the Clinton stage, and in New York the formation is known as the Furnaceville ore. Outcrops occur from New York, through Pennsylvania to southern Virginia, and others of corresponding age occur also in Alabama. There are several beds at different horizons in the formation, varying from a fraction of an inch to about 40 feet in thickness, though beds with a thickness of as much as ten feet are the exception. This ore is believed to be a chemical precipitate deposited in marshes and lagoons along the shore, the iron having been leached by streams from igneous rocks, over which they flowed, and brought to the sea. Fossil fragments are commonly found in the ore with the shell substance replaced

by the hematite, and so the ore is termed "fossil" iron ore. The name "pea" or "oölitic" iron ore is also applied to it because some beds are made up of rounded grains of a concretionary nature.

The lower beds of the Upper Silurian (the Salinan) through the Appalachian region are missing south of Virginia, the uppermost Silurian beds resting upon the Middle Silurian (Niagaran) except, perhaps, in southwestern Virginia. No typically marine Salina deposits are known anywhere. The elevation of the land and the withdrawal of the sea at the close of the Niagaran rejuvenated the rivers of Appalachia, and pebble and sand deposits were built up in the Appalachian trough, the latter now forming typical red beds through the alteration of the iron content. In central and western New York, in northern Ohio, in Michigan and parts of Ontario the Salina beds are represented by shales and lime muds alternating with salt and gypsum. In southern Michigan and adjoining areas the Salina formations are developed to their greatest thickness. In New York an extension of the red beds of the east underlies the salt beds, but dies away westward (Vernon shale). As mentioned above, the indications are that the Salina beds were accumulated in shifting lagoons or shallow arms of the sea, partially cut off from the sea by a barrier and surrounded by a desert region due to an arid climate. In time concentration of water in these lagoons became so great that common salt and other salts were precipitated. In this way pure salt deposits could accumulate to considerable thickness, but at times they would be overlain by muds brought into the lagoons by desert streams swollen by heavy rains. The salt

deposits of New York, southern Michigan and Ontario are very important sources of salt. In New York State beds of salt occur aggregating 50 to 100 feet in thickness and beds of pure salt have been found with a thickness of 40 to 80 feet.

The small, shifting nature of late Silurian seas has been touched upon above. Corals showing an Arctic origin occur and coral reefs form again in some areas. The Cobleskill limestone of New York marks an eastward extension of this reef fauna, although reef conditions are seldom found. The Cobleskill includes many corals of types characteristic of formations of this age in Michigan, belonging to a northern fauna. A persistent Middle or Southern Atlantic fauna of small brachiopods, *Leperditias,* pelecypods and *Tentaculites* occupied the southern part of the Appalachian trough and extended up into eastern New York (Manlius). In the northern end of the Atlantic trough (Nova Scotia) there was an Atlantic fauna, essentially that of the Upper Silurian of England.

The Silurian of western North America is not well known and apparently is poorly developed in the United States. In the Cordilleran area of Canada there was a deep trough in which between 2000 and 3000 feet of dolomites and limestones were deposited, and in the southern Cordilleran sea 200 or 300 feet of Silurian limestones were deposited in the Great Basin area (Nevada, Utah), also a considerable thickness of Silurian graptolite shales in Idaho. The Middle Silurian is represented in western Texas by a moderate thickness.

Besides New York State other important regions for the Silurian are Wisconsin, Michigan and Ohio in the interior; eastern Canada, especially the Island of An-

ticosti in the Gulf of St Lawrence; and the middle and southern Appalachian area. Silurian rocks cover large areas on the south shore of Hudson bay. In the eastern part of North America Silurian beds are found resting unconformably upon folded and eroded Ordovician strata; in the middle states unconformably upon Ordovician or older rocks where the Silurian seas overlapped the area covered by the Ordovician seas. In the western region (Montana, Utah) the strata of Ordovician, Silurian and Devonian seem to be conformable, thus falsely suggesting unbroken deposition in this area. Silurian rocks are far thicker in the east than in the west or in the interior, especially along the Appalachian range. The thickness of the limestones in the west and the interior are given above, also the thickness of the Appalachian trough deposits in Pennsylvania (mainly clastics, 6500 feet), from which area the Silurian materials thin rapidly to the south and north. The Silurian is widespread in the Acadian trough where 4000 feet of shales and sandy limestones occur. Farther south at Black Cape, Bay of Chaleur, Quebec, 7000 feet of deposits occur, here terminated by lava flows. Translated into terms of limestone deposits, Silurian deposits are the equivalent of 3000 to 4500 feet of limestone.

The Silurian was a quiet period. Volcanic activity was rare (southern Maine) and only in a few places do igneous intrusions occur in North America. Here the close of the period is marked by no disturbance and it is generally believed that deposition continued uninterruptedly into the Lower Devonian, though in certain areas unconformities have been noted. In Europe and other continents mountain building marked

the close of the Silurian. Among the mountain ranges formed were the Caledonian ranges of Great Britain which extended across Ireland and Scotland to northern Spitzbergen.

In addition to the fossil iron ores of the Clinton and the gypsum and salt of the Salina beds the Silurian (upper) is rich in dark-blue, impure, magnesium limestones of shallow-water origin, the waterlimes which are the natural cement rocks that were formerly so extensively quarried for the making of portland cement.

Life. During the Silurian four faunal provinces were represented in the continental seas: the Arctic, the Atlantic, the Southern (Gulf of Mexico) and the Cordilleran which is not well known but is believed to be Pacific. An important center of origin was the Arctic, which during Lower and Middle Silurian extended almost as far south as the Ohio river and included a large part of the northern interior area of the continent. The Arctic waters were warm and corals grew abundantly in the Arctic region as well as in Canada and the Michigan-Wisconsin area. The fauna shows a connection with the Baltic area of northern Europe and indicates a connection with this region by way of the St Lawrence trough and Greenland. The fauna of the Atlantic province entered the interior by way of the northern end of the Appalachian trough, then in communication with the North Atlantic. Many of the species of this province also occur in the rocks of western Europe, especially England, since that area, too, communicated with the North Atlantic. The fauna of this province is most abundantly found in the rocks of Anticosti Island in the Gulf of St Lawrence.

In other parts of the Appalachian trough this fauna occurs, and the forms are found alternately interbedded with types that came in from the south (Southern or Gulf of Mexico). At times the Atlantic fauna also spread westward to Kentucky and southern Ohio where it alternates with the coral fauna of that area. This westward invasion is most completely exemplified in the fossils of the Clinton limestone. The Southern province has the longest and least broken record and is best known. From it organisms spread into the epicontinental seas of the southern interior and the Appalachian trough.

The marine faunas of the Lower Silurian (Richmond and Alexandria or Upper Medina) show a total number of species that falls little, if any, short of 700 species (400 Richmond) and may run nearer 900 than 700 (Ulrich). The fauna of the Middle Silurian, especially at the time of greatest submergence, was represented by a great variety of forms, the faunas of the various provinces at this time having the greatest number of species in common. Over 2500 species of invertebrates have been described for North America, of which the corals, bryozoans, brachiopods, crinoids and trilobites are the most common. The plant *Receptaculites* is not uncommon in some localities (Clinton beds). There were *marine plants,* especially lime-secreting algae, but as usual in marine sediments the record is meager. Very primitive *land plants* have been reported from the Silurian but these records are not undoubted. There were several remarkable forms among the *sponges,* among them the concavo-convex (saucer-shaped) *Astraeospongia* and the nearly spherical *Astylospongia,* which also occurs quite abundantly in Upper

Chazyan (Lower Ordovician) formations in Appalachian faunas of Atlantic origin. *Graptolites* are chiefly of unusual types (with the cups or thecae on one side of the axis, as *Monograptus, Cyrtograptus.*) They are still common in Europe at this time, but are not often found as fossils in North America. *Corals* are abundant in the limestones. They formed reefs, which are not common until the Middle Silurian; but the Silurian coral reefs are seldom of great thickness. Associated with the coral reefs during Middle Silurian (Guelph) time was a large number of species of thick-shelled animals, chiefly gastropods, that found it easy to extract the lime occurring abundantly in the warm waters. The honeycomb coral *Favosites* makes practically its first appearance with many species. An abundance of the chain coral *Halysites* and the tube coral *Syringopora* is characteristic, though both types appear rarely in Lower and Middle Ordovician formations. Besides these there are many remarkable single corals. *Hydrocorallines,* quite unlike those of the Ordovician *Stromatoporas,* are abundant and are characteristic types. The *bryozoans* are numerous in the shaly and pure limestones and many of them show clearly their derivation from Ordovician forms; but others are of types that appear now for the first time, among them lacelike zoaria of *Fenestella, Polypora* and *Hemitrypa* which attained the high points of their development in the succeeding Devonian and Mississippian periods. Between 300 and 400 *brachiopod* forms have been described for North America. This fauna is on the whole very characteristic. *Strophomena* and *Rafinesquina* are replaced by *Strophonella* and *Stropheodonta* respectively. In the Orthis group are *Dalmanella* and *Rhipidomella.*

The smooth-shelled, biconvex *Whitfieldellas* are present. The *Spirifers* appear almost abruptly in the Clinton (Middle Silurian). They are still for the most part small forms though there are a few large ones (*S. niagaraensis, S. radiatus*). Rhynchonelloid (*Camarothoecia, Rhynchotreta*) and pentameroid (*Pentamerus*) shells are abundant and there are some specialized forms (*Trimerella*). *Pelecypods* are in general less distinctive. There are many types of *gastropods,* both low and high-spired and, especially in the Upper Silurian, they are often strongly ornamented. Among the *cephalopods* the most characteristic forms are the ringed orthoceran types (*Dawsonoceras*) and curved forms with contracted aperture (*Phragmoceras, Gomphoceras*). There are also many forms with spiral coil (*Trochoceras,* etc.) The development of cephalopods (nautiloids) in European seas is much greater. The *conularids* are represented by the genus *Conularia* and the *pteropods* by *Tentaculites* so characteristic of our Manlius. Among echinoderms, *crinoids* and *cystoids* are abundant. Crinoids are better developed than in the Ordovician and are so numerous that their stems and "joints" constitute an important part of certain limestone beds. About 400 forms have been described from the American Silurian. Characteristic forms among the crinoids are *Ichthyocrinus* and *Eucalyptocrinus;* among the cystoids, *Caryocrinus* and *Callocystis. Blastoids* (*Troostocrinus*) are present, but they are rare in both the Silurian and the Devonian. Other echinoderms are rare. *Trilobites* are still numerous, but much less so than in the Ordovician. They are, for the most part, species of genera which have survived from the preceding period. Over 100 species have been de-

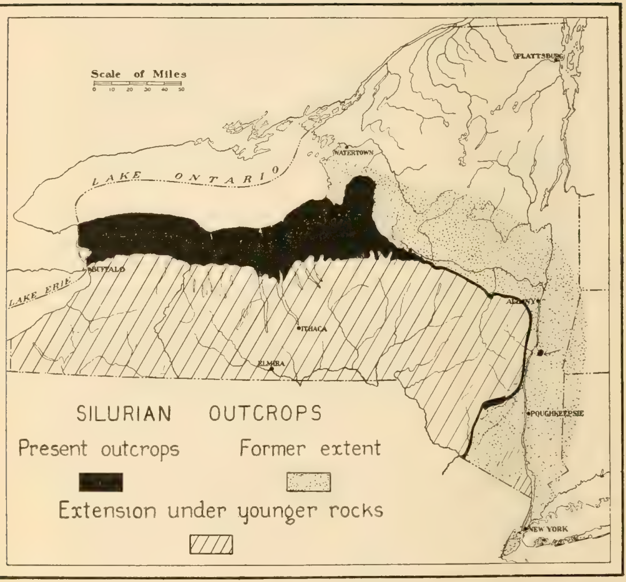


Figure 42 Silurian outcrops. The probable former extent of the seas of this period and the extension of the formations under those of younger age are shown.

scribed for America. Some of the common genera are *Dalmanites, Calymene, Illaenus, Lichas, Bronteus, Phacops, Proëtus, Encrinurus.* The genera *Dicranopeltis, Trochurus, Staurocephalus* and *Deiphon* are especially characteristic. Other crustaceans, especially *ostracods,* are present. *Eurypterids* or "sea scorpions" are at the height of their development in the Silurian and many genera occur (*Eurypterus, Pterygotus, Stylonurus* etc.). They lived in the freshening lagoons of Salina (Upper Silurian) times and became buried in the calcareous muds (waterlimes) of the shoal waters. The most ancient representative (*Hemiaspis*) of the *horseshoe crab* occurs in the European Silurian. The oldest *scorpion* (air-breathing animal) is known from Upper Silurian deposits. Other air-breathing animals found in the late Silurian are the thousand-legged worms (*myriopods*). *Fishes* occur for the first time in basal Silurian formations (Harding sandstone). They are found in Upper Silurian deposits inhabiting fresh-water streams, but they are very rare in America. Sharks of a very primitive character lived in Silurian seas, but very little is known about them.

Climate. The climate of the Silurian must have been temperate to warm and fairly uniform over the entire world, judging by the varied life and the deposits of limestones and dolomites, even in the Arctic regions. The reef-building corals are about the same everywhere, and such characteristic forms as the chain coral (*Halysites*) and the honeycomb coral (*Favosites*) are similar in all regions, occurring also in the Arctic area. During a portion of the period (Salina) an arid or dry climate prevailed probably over considerable area.

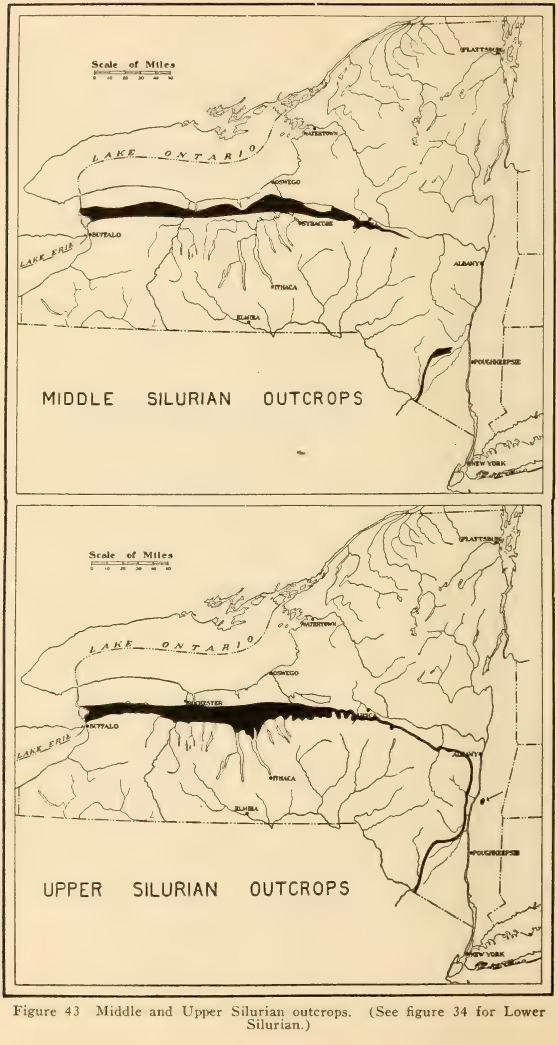


Figure 43 Middle and Upper Silurian outcrops. (See figure 34 for Lower Silurian.)

New York formations. At the close of the Ordovician New York State was practically dry land and undergoing erosion. The only very high lands were found in the Taconic range along the eastern side and the central Adirondacks. Silurian rocks are found outcropping in a narrow belt along the west side of the Hudson valley extending to the Helderberg mountains southwest of Albany (figures 34, 42, 43). Here the beds turn abruptly westward, following the south side of the Mohawk valley, and south of Lake Ontario the belt becomes much wider. Silurian rocks underlie the younger rocks (figure 44) throughout the rest of the State, which indicates that through much of Silurian time the present area of New York south of Lake Ontario and the Mohawk valley and west of the Hudson river was submerged. As shown by the tables of formations the central and western parts of the State were submerged first. The first formation deposited in central New York was the Oneida conglomerate of lower Clinton age (base of Middle Silurian); in southeastern New York, the Shawangunk grit or conglomerate which is now considered to be as young as Clinton and has been placed in the Medinan (Lower Silurian). It was not until late in the period that the sea encroached upon the Hudson valley to the western slopes of the Taconic mountains. There is no evidence that the northern Adirondack area was submerged during Silurian times. It was probably elevated at the time of the Taconic Disturbance (close of Ordovician) and has remained dry land ever since except for local submergence during the Pleistocene (Quaternary). Both Silurian and Devonian strata undoubtedly lapped upon the southern Adirondack area, but

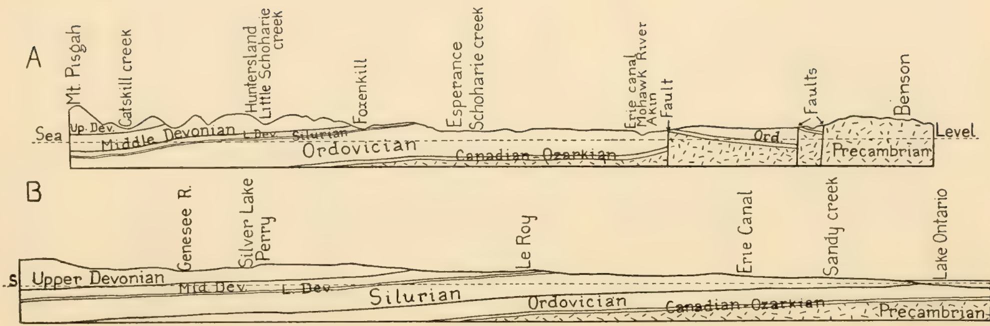


Figure 44 *A* Section from Mount Pisgah in the Catskills (Schoharie county) north to Benson (Hamilton county). Horizontal scale: approx. ½ inch = 5 miles. Vertical scale: approx. ½ inch = 5280 feet. *B* Section through western New York along the 78th meridian. Horizontal scale: approx. ½ inch = 5 miles. Vertical scale: approx. ½ inch = 5280 feet.

to what extent can not be determined. Thus we see that during early Silurian the sea claimed only central and western New York, but in the late Silurian practically all the State south and west of the Adirondacks was under water. A maximum of between 2600 and 3000 feet of deposits was laid down in New York State in Silurian times, the greatest thickness represented by shales and sandstones. The classification of the New York formations follows, the dashes indicating missing beds in the various sections.

SILURIAN SYSTEM

Western	*West Central*	*Central*
Cayugan (Upper)	**Cayugan** (Upper)	**Cayugan** (Upper)
——	Manlius l.s.	Manlius l.s.
——	Rondout w.l.	Rondout w.l.
Cobleskill dol. (Akron)	Cobleskill dol. (Akron)	Cobleskill dol.
Salina beds	Salina beds	Salina beds
Bertie w.l.	Bertie w.l.	Bertie w.l.
Camillus sh.	Camillus sh.	Camillus sh.
Syracuse salt	Syracuse salt	Syracuse salt
Vernon sh.	Vernon sh.	Vernon sh.
Pittsford sh.	Pittsford sh.	Pittsford sh.
Niagaran (Middle)	**Niagaran** (Middle)	**Niagaran** (Middle)
Lockport dol. (incl. Guelph dol.)	Lockport dol. (incl. Guelph dol.)	Lockport dol. (incl. Guelph dol.)
Clinton beds	Clinton beds	Clinton beds
Rochester sh.	Rochester sh.	Rochester sh.
Irondequoit l.s.	Irondequoit l.s.	Shales
——	Williamson sh.	Williamson sh.
	(Wolcott ore)	
——	——	——
——	Wolcott l.s.	Wolcott l.s.
——	Sodus sh.	Sodus sh. ?
	(Sterling Sta. ore)	
——	Bear Creek sh.	Bear Creek sh.
Reynales l.s.	Reynales l.s.	Reynales l.s.
	(Furnaceville ore)	
Maplewood sh.	Maplewood sh.	Maplewood sh.
Thorold s.s.	Thorold s.s.	Oneida cgl.
Medinan (Lower)	**Medinan** (Lower)	**Medinan** (Lower)
Upper Medina beds	——	——
Albion: Red sh. and s.s.		
Albion: Whirlpool s.s.		
Queenston sh.	Queenston sh.	——

SILURIAN SYSTEM

East Central		*Eastern*
Cayugan (Upper)		**Cayugan** (Upper)
Manlius l.s.		Manlius l.s.
Rondout w.l.		Rondout w.l.
Cobleskill l.s.		Cobleskill l.s.
Salina beds		Salina beds
Bertie w.l.	*Brayman sh.	Rosendale w.l. Wilbur l.s.
Camillus sh.		Binnewater s.s.
Syracuse salt		
Vernon sh.		High Falls sh.
Pittsford sh.		(Longwood sh. of Orange co.)
Niagaran (Middle)		**Niagaran** (Middle)
Lockport dol.		——
Clinton beds		Clinton beds
Rochester sh. and s.s.		
(Fossil ore)		
Shales and s.s.		
Williamson sh.		
(Oölitic ore)		
Middle Clinton sh. and s.s.		Shawangunk cgl.
——		
Sodus sh.?		
——		
——		
——		
Oneida cgl.		
Medinan (Lower)		**Medinan** (Lower)
——		——
——		——

* Brayman shale probably represents a residual soil of the Ordovician.

The *Queenston shales* (Grabau '08; *Lewiston*, Chadwick '08) were named from the exposure in the banks of the Niagara river at Queenston, Ontario. This formation consists of red and green shales and green and gray sandstone and, as stated above, is part of a river delta deposited in the Appalachian trough during the submergence in Richmond (Lower Medinan) times and extending from southern Virginia and Maryland through Pennsylvania, New York and southern Ontario. In New York these beds have a maximum thickness of 1200 feet and are confined to the western part of the state where they are well exposed in the Niagaran area (Lewiston,

Queenston). This formation was included in the "Medina sandstone" of Vanuxem ('40), representing the lower red shales. The shales are friable and the ultimate product of weathering is a sticky red clay. No fossils have been found in the New York beds, but it has been reported that beds containing Richmond fossils are intercalated in the Queenston shale in Ontario. The Queenston shales are the stratigraphic equivalent of the *Juniata formation* (Darton '96) of Pennsylvania, Maryland and Virginia.

The *Upper Medina beds* include the Lower Silurian formations above the Queenston shales, that is, the sandstones and shales between these beds and the gray band or upper sandstone. To these sandstones and shales the name *Albion sandstone* has been given. The original name, "Medina sandstone" (Vanuxem '40), for all these beds was taken from exposures along Oak Orchard creek at Medina, Orleans county. From these beds also is derived the name for the series, which has also been termed the Oswegan group (Clarke and Schuchert '99), from the widespread occurrence of the members in Oswego county, though this latter term for the group is not now properly in use. The *Albion sandstone* (Clarke) which has a maximum thickness of about 120 feet, consists of a basal, coarse, white sandstone, the *Whirlpool sandstone* (Grabau '09), with a maximum thickness of 20 feet, and an upper series of alternating red and gray shales and sandstones with a thickness of 100 feet, more or less. On top of these beds is a hard, gray sandstone, the Thorold sandstone, which has been included in the Medina beds, at the top, as part of the Albion sandstone but was originally put by Vanuxem at the base of the Clinton, of which it is really the initial deposit of coarse sands left

on the surface after weathering of the underlying Medina sandstones. To these shales and sandstones below the Thorold have also been given the names *Grimsby sandstone* from Grimsby, Ontario, and the *Cataract formation* (Schuchert '14), named from its occurrence at the cataract of the Credit river, Ontario. The Grimsby and Cataract are largely equivalent and interfingering local phases of the Upper Medina and not strictly separable time divisions of the group. The Whirlpool sandstone is the clastic base of the Cataract. At, or rather just above, the top of the typical Upper Medina shales (Grimsby) in the Thorold sandstone is found the worm trail *Arthrophycus alleghaniensis* (*harlani*), a very characteristic and widely distributed fossil that marks the beginning of the Clinton group. The brachiopod *Lingula cuneata* is a characteristic Upper Medinan fossil, occurring in abundance in certain beds in the light-colored sandstone. There is a sparse fauna in the Albion sandstone, but while a large part of this formation is barren, a fair fauna has been found in the quartzose beds and in part listed (Ulrich '26). No fossils have been found in the lower beds of these Upper Medina sandstones; in the upper 25 or 30 feet a small fauna has been found including bryozoans, brachiopods (*Whitfieldellas* as W. *oblata* etc.) and gastropods (*Bucanella trilobata, Pleurotomaria* (*Euconia?*) *pervetusta etc.*)

From the middle or typical part of the Upper Medina sandstone at Lockport has come a considerable fauna (44 listed; Ulrich '26) of bryozoans (*Phaenopora explanata, Lioclemella* cf *ohioensis, Helopora* cf *fragilis* etc.), brachiopods (*Lingula cuneata, Whitfieldella oblata, Rhynchotrema plicata* etc.), pelecypods (*Ctenodonta, Modiolopsis, Cleidophorus, Ischyrodonta, Orthodesma,*

Rhytimya, Cyrtodonta etc.), gastropods (*Pleurotomaria* sp., *Hormotoma* sp., *Lophospira litorea, Bucanella trilobata*) and cephalopods (*Oncoceras gibbosum, Orthoceras* sp.). The characteristic ostracod (crustacean) *Leperditia cylindrica* also occurs. This fauna in its pelecypods exhibits decidedly Richmondian (Lower Medina) affinities, and they constitute considerably more than a majority of the total number of species.

The *Clinton beds* or *formation* (Vanuxem '42) was named from the type section at Clinton, Oneida county, and has a maximum thickness of 350 feet. In this group, as a basal deposit, is now included the Thorold sandstone and Oneida conglomerate previously regarded as the top of the Medina. The members of the Clinton formation extend as a belt from Otsego county to the western limits of the State and form the lower part of the Niagaran series (Clarke and Schuchert '99, from the Lockport (Niagaran) limestone), the upper part being the Lockport group with the Guelph dolomite as the top member of the formation (figures 45, 46).

The Clinton group in New York is divisible into three main parts, termed for the present Lower Clinton, Middle Clinton and Upper Clinton; and each of these formations, except perhaps the middle one, is again divisible into two or more lithological members (Hartnagel '12; Chadwick '18). These three divisions of the Clinton differ very decidedly in geographic distribution and are distinguished by strongly marked faunal differences which are maintained and clearly recognizable from New York to Alabama. Ulrich's studies of the ostracods have for the first time cleared up the confusion that before existed in the correlation of the Clinton beds (Ulrich and Bassler '23; 342–49). Study of the field relations of the Clinton ostra-

Figure 45 Lower and Middle Silurian rocks. Upper Medina beds at water's edge, Clinton beds in the middle, Lockport formation at top. Niagara gorge below the bridge, Niagara county. (Photograph by J. A. Glenn)

cods has brought out the fact that they occur in more or less clearly distinguishable zones. Nine of these zones have been recognized (Ibid; 349–91), three for each of the major divisions of the Clinton (Lower Clinton: 1 *Zygobolba erecta*, 2 *Z. anticostiensis*, 3 *Z. decora;* Middle Clinton: 4 *Z. emaciata*, 5 *Mastigobolbina lata*, 6 *Zygosella postica;* Upper Clinton: 7 *Bonnemaia rudis*, 8 *Mastigobolbina typus*, 9 *Drepanellina clarki* zones). These fossil zones serve mainly in giving an approximate indication of particular horizons in an otherwise very uncertain sequence of deposits. Favorable exposures, that is, perfectly exhibited sections, are seldom found and the successive beds of shale and sandstone are much alike in lithologic character and many are practically barren of organic remains.

The character and relations of the Clinton divisions in New York may be pretty well understood from a study of the sections exposed in the gorge of the Genesee at Rochester (figure 46) and at Clinton, the type locality. The Middle Clinton with its wealth of very characteristic ostracods, which occurs at the type locality, is not found in the Rochester section and, indeed, is restricted to east of Lakeport.

In western New York the Lower Clinton begins with the *Thorold sandstone* ("Gray Band"). This is a hard, gray sandstone, five to 12 feet thick, named from its occurrence at Thorold, Ontario (Grabau '13). A few fossils are present in this sandstone, among them bryozoans and the brachiopod *Rhipidomella*. At Niagara Falls this band rests on mostly red sandstones of the Upper Medina, representing the closing marine stage; between Lockport and Rochester it rests upon various older sandstones of the Upper Medina; and going eastward

rests upon progressively older (lower) beds. In central and east central New York the basal bed is known as the *Oneida conglomerate* (Vanuxem '40). It rests upon the Upper Medina beds in Oswego county; disappears westward in Wayne county; and in Otsego county the eastern extension in the Mohawk valley rests upon the Frankfort shales. The excellent exposures in Oneida county in the vicinity of the village of Verona gave it the name. This conglomerate has a maximum thickness of 50 to 70 feet and carries the characteristic fossil, *Arthrophycus alleghaniensis,* also found in the Thorold sandstone, which is not, as commonly believed, an indication of Medinan age but, on the contrary, always occurs in the initial deposit of the Clinton and not in the Medina beds beneath the erosion contact.

The *Maplewood shale* (Chadwick '18) named from Maplewood Park, Rochester, is a green, unfossiliferous shale above the Thorold, with a thickness of 21 feet in the Rochester section where it is best displayed. This bed was formerly called the Sodus shale but has been shown to be older (Chadwick). It pinches out about a hundred miles or so east of Rochester, somewhere between Lakeport and Verona, Oneida county. Above the Maplewood shale in the Rochester section is a tripartite limestone about 18 feet thick, called the *Reynales limestone* (Chadwick '19) from Reynales Basin, near Gasport, Niagara county. The lower four feet contain a representation of the Furnaceville iron ore and are known by their fossils as far west as Hamilton, Ontario. This lower part is the typical Reynales limestone, consisting of thin limestone and shale containing near the top minute gastropods (*Cyclora* and *Microceras*) and characterized in the upper half by a fair representation

of the brachiopod *Hyattidina congesta.* The overlying thicker beds which for the present are also referred to the Reynales limestone consist of dark-gray or bluish, even-grained, sometimes dolomitic limestone. The upper five feet contain some nearly pure limestone layers filled with the brachiopod *Pentamerus oblongus,* from which formerly this formation was called the "Pentamerus limestone" of the Clinton (Hall). The middle member is the most highly dolomitic and most persistent, but sparingly fossiliferous, the brachiopod *Stricklandinia canadensis* being the only species that is particularly characteristic, though *Anoplotheca hemispherica* makes its appearance for the first time. The fauna of the Reynales limestone is of southern origin, as also the later Wolcott. While the name is provisionally adopted for all of this limestone, it is believed (Ulrich) that this name should be restricted to the lower four or five feet (the typical Reynales) which alone are present at Reynales Basin. This formation pinches out about 100 miles east of Rochester at some place beyond Lakeport. The Reynales has been identified (Hall; later Hartnagel) with the Wolcott limestone, but the latter does not extend as far west as Rochester.

The *Furnaceville iron ore* (Hartnagel '07) was named from its typical development at Furnaceville in Wayne county where the ore has been worked for years. This ore bed does not occur in the Niagara section but is 14 inches thick in the Rochester section, increasing farther east to a maximum of two and one-half feet. The Clinton ore beds going west to east progressively die out eastwardly, new and always higher beds coming into the section. The oldest (Furnaceville) alone is present in the Rochester belt. At Wolcott, Wayne county, the ore

occurs at the base of the Williamson shale (the Wolcott Furnace ore bed). Another ore bed is also present in the basal Sodus shale (Sterling Station ore). The ore continues east of Wayne and Cayuga counties and is found in the Clinton section where the highest ore bed occurs. This highest bed is found at the base of the Rochester shales and sandstones and is the "fossil" ore, and the only one that has properly been so named. The "oölitic" ore bed at the base of the Williamson shale in this section is the next older and the only one now mined at Clinton. The iron ore of the Clinton is hematite and is always red in color. It has been variously termed "fossil iron ore," because of the replacement of fossils such as crinoids and bryozoans by the iron ore, and "oölitic" or "lenticular" ore, because of the presence of lenticular-shaped spherules in the ore. Mines are located in Ontario, Wayne county, Sterling Station, Cayuga county, and near Utica in the town of Kirkland.

Above the Reynales limestone in the Rochester section is an 18-foot bed of purple and olive shales with thin plates of fossiliferous limestone which has received the name *Bear Creek shale* (Chadwick '19) from exposures along Bear creek, near Wolcott. The pearly lustre is due to shells of the exceedingly abundant brachiopod *Anoplotheca* (*Coelospira*) *hemispherica.* Also in the shale occur fairly characteristic pelecypods as *Modiolopsis subalata, Orthodesma curtum* etc., a trilobite, *Phacopidella trisulcata,* and well-preserved ostracod valves of which the most important are five species of *Zygobolba* (*Z. anticostiensis* zone). This formation has a thickness of 20 feet at Wolcott, and pinches out before reaching Lakeport. These shales have been included with the overlying dark graptolitiferous shales in the

Williamson shale, but the true Williamson overlies the true Wolcott limestone which does not appear in the Rochester section, as also the true Sodus beneath the Wolcott. The *Sodus shale* (Hartnagel '07) like the Bear Creek shale consists mainly of purple shales with thin layers of highly fossiliferous pearly limestone, and has a fauna of the same general aspect. The name is from the town of Sodus in Wayne county where there is a thickness of 55 feet or more. This shale is not present in the Rochester section. At Wolcott, Wayne county, it has a thickness of 40 feet; at Lakeport, Oneida county, of 31 feet, thence thinning eastward. In the Clinton section the Lower Clinton is perhaps represented only by the initial deposit of Oneida conglomerate (see discussion of Middle Clinton). Varieties of two species of *Anoplotheca* are found (*A. hemispherica* and *A. plicatula*). Lobate forms (four species) of the ostracod genus *Zygobolba* occur. The *Wolcott limestone* (Hartnagel '07) receives its name from Wolcott in Wayne county where it has a thickness of 22 feet. Westward it pinches out rapidly, being entirely absent in the Rochester section. In an easterly direction it thins less rapidly, having a thickness of 18 feet at Lakeport, but it does not appear in the section at Clinton (Oneida county). The occurrence of the brachiopod *Pentamerus oblongus* has given this dark gray, fine, even-grained, sometimes dolomitic limestone, the name "Upper Pentamerus." The Sodus shale below with its two species of *Anoplotheca* and variety of ostracods is a typical Atlantic Silurian association; while the Wolcott limestone fauna has no ostracods, lacks the Anoplothecas and is made up of types of bryozoans and brachiopods that came in with

an invasion from the south. The bryozoans comprise about half the fauna.

The *Middle Clinton beds* form a lenticular mass wedging in from the east between the base and the upper Clinton. Its eastern edge is "finally overlapped by the Upper Clinton so that in the eastern part of Herkimer county the latter and the initial deposit of Oneida conglomerate constitute the whole of the Clinton group as there developed" (Ulrich). At Clinton there are 125 feet or more of greenish shales and sandstone layers constituting the Middle Clinton. The top is marked by the base of the oölitic iron ore at Clinton. Its base is somewhat doubtful. It may extend down to and include the Oneida conglomerate or the basal part may include a thinned representation of the Lower Clinton beds. For these beds of shale and sandstone the names *Kirkland beds* (Ulrich '17) and *Sauquoit beds* (Chadwick '17, '18) have been proposed. The recognition of the Middle Clinton in New York is based mainly on the fossil evidence. There is a wealth of characteristic ostracods. The Middle Clinton contains other fossils besides the ostracods, but they are seldom abundant or well-preserved and not many kinds have been found. The ostracod *Mastigobolbina lata* is the most characteristic of the Middle Clinton forms. Other species are *M. vanuxemi, M. clarki* and *Zygobolbina conradi.*

The Upper Clinton includes the Williamson shale, Irondequoit limestone and Rochester shale. In the Clinton section the oölitic iron ore and the 18 feet of bluish or greenish shale above are correlated with the Williamson; the nine feet of clayey suboölitic limestone (two feet) and calcareous sandstones and arenaceous shales above to the Irondequoit limestone. The Red flux ore bed

Figure 46 Lower and Middle Silurian rocks. Medina beds (mainly red beds) below; above, Clinton beds with Rochester at the top. Genesee gorge, near Rochester, Monroe county. (Photograph by J. A. Glenn)

above these beds represents the lower half of the Rochester, leaving the overlying sandstones in the Clinton section to represent higher parts of the Rochester. As stated above, east of Clinton the overlapping of the Middle Clinton by the Upper Clinton finally, in Herkimer county, leaves the latter (as indicated by the fossils) and the Oneida conglomerate as representatives of the Clinton there. There is a decided faunal break between the Middle and Upper Clinton in New York, as well as in sections elsewhere, and the Rochester fauna is a mixture of Atlantic and southern faunas. The *Williamson shale* (Hartnagel '07) receives its name from the town of Williamson in Wayne county, and is well developed in this and Monroe county. In the Rochester section it is represented by five or six feet of dark shale containing an abundance of *Monograptus clintonensis,* the most characteristic fossil of the Williamson shale. It has not been traced far west of Rochester. Eastward the shale increases to its supposed maximum of 105 feet at Lakeport (deep well) and then thins rapidly to the Clinton section where it is thought to be represented by the oölitic iron ore and the 18 feet of interbedded soft shale and harder calcareous shale above the ore. The Williamson shales are greenish in color and there are a number of interbedded purple bands. These shales are quite fossiliferous. Besides the graptolite the Williamson has the first Clinton occurrence of the brachiopod *Plectambonites* (probably *P. elegantulus*) ; and a third characteristic fossil is a supposedly new species of *Ischadites* (plant?), conical or oval bodies, inclosing a central cavity with a small summit aperture. The other fossils show a decidedly closer alliance with succeeding Irondequoit and Rochester species than with Middle and Lower Clin-

ton species. At Clinton in the limy zone above the ore occur the brachiopods *Dalmanella elegantula, Bilobites biloba,* and *Nucleospira pisiformis,* prolific members of the two succeeding formations (Irondequoit, Rochester). The coral *Palaeocyclus rotuloides* is abundant and striking, and the ostracods *Mastigobolbina punctata* and *Plethobolbina typicalis* also occur here. The *Irondequoit limestone* (Hartnagel '07) was named from the town of Irondequoit, Monroe county. The formation is still recognizable east of Wayne county, but has become so shaly as to be no longer recognized as a limestone. In the Niagara section the limestone directly overlies the Reynales limestone (Wolcott of authors). This member is a light gray, coarsely crystalline limestone with a maximum thickness of 15 to 17 feet and consists of numerous layers of limestone separated by bands of shale. It is also characterized by the occurrence of reef structure, some confined to the limestones and others running up into the Rochester shale above. Its highly fossiliferous character is in contrast to the limestone formations below. More than 100 species have been recorded from the reefs, the most abundant being the brachiopod *Whitfieldella nitida* and the trilobite *Illaenus ioxus.* Other common forms include the brachiopods *Atrypa reticularis, Camarotoechia neglecta, Spirifer crispus, Leptaena rhomboidalis* and the trilobite *Calymene niagarensis.*

The *Rochester shale* member of the Clinton formation consists of soft bluish gray argillaceous shale (Hall '39; Conrad) with a maximum thickness of about 100 feet. The shales were named from the city of Rochester. For a time they were known as the Niagara shales, and then the name of Rochester shales was revived. In the

Rochester region the shale is about 85 feet thick. Complete exposures are found here in the Genesee gorge and in the Niagara gorge (60 feet). The upper part of these shales is lighter in color and characterized by the occurrence of thin layers of limestone, one to three inches thick. This shale is known as far eastward as Oneida county and probably extends into Herkimer county where a similar shale occurs below the concretionary layer of the Lockport dolomite. The lithologic change from the Irondequoit limestone to the Rochester shale is very abrupt, but there is a strong affinity between the two faunas. The Rochester shale is very rich in fossil remains. Fossils are abundant in the lower part of the shales and crinoids here are among the most abundant and characteristic forms (*Caryocrinus* (cystoid), *Eucalyptocrinus, Ichthyocrinus, Lecanocrinus etc.*). Toward the top fossils are less abundant and the upper few feet are practically barren. Higher up the fossils are chiefly bryozoans. More than 80 species of bryozoans alone have been described from this fauna, about one-third of the total number of species. A characteristic form is *Phylloporina asperato-striata.* Besides the crinoids and bryozoans, these shales abound in species of corals (*Enterolasma caliculum, Favosites*), brachiopods (*Dalmanella elegantula, Nucleospira pisiformis, Stropheodonta profunda, Rhipidomella hybrida, Orthis flabellites, Plectambonites transversalis, Leptaena rhomboidalis, Rhynchotreta cuneata* var. *americana, Spirifer niagarensis, Whitfieldella nitida, Atrypa reticularis*), pelecypods (*Pterinea emacerata, Leiopteria subplana*), gastropods (*Platyceras niagarense, Diaphorostoma niagarense*) and trilobites (*Calymene niagarensis, Illaenus*

ioxus, Dalmanites limulurus, Homalonotus delphinocephalus, Arctinurus (*Lichas*) *boltoni*).

The *Shawangunk conglomerate* (Mather '40) is the basal formation in eastern New York. On the basis of the eurypterids found at Otisville, N. Y., in the thin beds of dark shales intercalated in the grit, together with other considerations, not faunal, this conglomerate was regarded as of the age of the Pittsford and the basal member of the Salina in the east (Clarke and Ruedemann '07, '12; Hartnagel '07). Later this formation was placed in the Medina (Van Ingen '11; Schuchert '16) because the then supposed Medina fossil, *Arthrophycus alleghaniensis,* was found at Otisville in the midst of the eurypterid beds; but the upper pink and reddish zones were considered of Clinton age and equivalent to the iron ore zones. Van Ingen ('11) considered it of Medina-Clinton-Niagara age. The latest view is that this basal Silurian deposit began earlier in Pennsylvania, and that as it overlaps northward upon the old land surface, its base is made by younger and younger beds so that in New York State the Shawangunk is mainly or entirely of Clinton age or younger (Ulrich). The Shawangunk conglomerate decreases in thickness northwardly from the Shawangunk mountains from which it takes its name and in which it reaches a thickness of 600 feet or more. It is gray to whitish, sometimes slightly greenish in color, and consists of conglomerates, grits and shales. It rests unconformably upon the Ordovician beneath and outcrops in the Kingston-Port Jervis area and in Orange county. Its occurrence in the latter area is the continuation of the *Green Pond conglomerate* of New Jersey. The shale partings of the Shawangunk are usually of insignificant thickness; in general the formation tends to

become more shaly in the upper portion. The sands and conglomerates constituting this deposit came from Appalachia to the east.

The *Lockport dolomite* (Hall '39) was named from its occurrence at Lockport, Niagara county, and it is known as far east as Steele's creek in Herkimer. The name is applied to the whole series or group of magnesian limestones or dolomites (including Gasport limestone, Guelph dolomite) deposited upon the Rochester shales and thinning eastward. For a time these limestones were also known as the Niagara limestones, just as the Rochester shales were known as the Niagara shales. The Lockport dolomite has a maximum thickness of about 140 or 150 feet in the Niagara area, and is dark gray to chocolate colored. There it carries the Guelph fauna at the top. At Shelby in Orleans county the section shows three feet of dolomite carrying the Guelph fauna appearing after 62 feet of Lockport; then occur 32 feet of Lockport followed again by eight to ten feet of dolomite with the Guelph fauna. The dolomite carrying the first Guelph fauna is known as the *Lower Shelby dolomite* and represents the first invasion of the Guelph fauna from the west; the second dolomite bed with this fauna has been called the *Upper Shelby dolomite* (Clarke and Ruedemann '03). Similar conditions exist at Rochester. The horizon of the Lower Shelby dolomite has been located in the Lockport section. About ten feet above the base of the Lockport is 20 feet of light gray to white, coarse-grained, semi-crystalline, pure limestone which contains an abundance of crinoid plates and stems and other fossils which give it a distinctive appearance in contrast to the sparingly fossiliferous beds above and below. This bed has been termed in the literature of the

region the "Crinoidal" limestone, "Lockport Encrinal" marble and "Lower Niagara" limestone, and is now known as the *Gasport limestone* (Kindle '13). The fauna of the Lockport dolomite (exclusive of the Guelph fauna) is not an abundant one. There is the normal Lockport fauna, derived from the Rochester fauna and much more common in the argillaceous facies, and the crinoid fauna (*Thysanocrinus, Ichthyocrinus, Eucalyptocrinus etc.*) mentioned above. *Stromatopora* and, locally, the corals *Halysites catenlatus* (*catenularia*) and *Favosites favosus* are characteristic. At Shelby the 32 feet of Lockport dolomite separating the Guelph faunas are free from Guelph fossils.

The *Guelph dolomite* (Bell '63) receives its name from Guelph in Canada. In New York it is a thin-bedded, black or steel gray dolomite that gives off a strong odor of petroleum when freshly fractured. About 15 feet seems to be the maximum thickness. The double occurrence at Shelby, Orleans county, has been mentioned above under the discussion of the Lockport group. The lower occurrence, the *Lower Shelby dolomite,* contains the purer Guelph fauna; the *Upper Shelby dolomite* has Lockport species included in its fauna. Farther west the Guelph part of the Lockport group appears only at the top, with a thickness of 140 feet in Canada. This formation is known as far east as Wayne county. A total of over 70 species are now known for the Guelph of New York and of these 17 also occur in the dolomite below. The Guelph dolomites are the last true marine deposits of Silurian time in New York. The Lockport sea was shallowing and gradually becoming more inclosed, with an accompanying increase in salinity and magnesian content of the sea water. Coral reefs became very abun-

dant and were favorable for the existence of life under new conditions and environment. The Upper Guelph horizon at Rochester and Shelby is characterized by fossil-bearing chert concretions. With increasing salinity the Guelph fauna, an invasion from the west, replaced the Lockport fauna and finally itself disappeared with the formation of the Salina sea. Two types of structure are represented in the Guelph fauna: large, heavy-shelled forms that occupied the more exposed areas of the coral reefs and small, thin-shelled forms that lived in more sheltered places (Lockport and Rochester forms mostly here). Characteristic Guelph fossils are the hydrocoralline *Stromatopora galtensis,* the brachiopod *Monomorella noveboracum,* the gastropods *Poleumita scamnata* and *Hormotoma whiteavesi* and the cephalopods *Trochoceras desplainense* and *Poterioceras sauridens.* Among the earlier forms that have carried over are the corals *Favosites niagarensis, Halysites catenulatus,* the brachiopods *Dalmanella* cf. *elegantula, Rhipidomella* cf. *hybrida Spirifer crispus,* and the trilobite *Calymene niagarensis.*

The Cayugan series (Clarke and Schuchert '99) constitutes the Upper Silurian, and includes the *Salina beds, Cobleskill limestone, Rondout waterlime* and *Manlius limestone.* Since the upper members are typically exposed along the north end of Cayuga lake and all the members cross Cayuga county, that name was assigned to the series.

The *Salina beds* (Dana '64) are the "Salina shales" of earlier authors and the present named divisions practically correspond to the four members of the reports of Vanuxem and Hall, who designated the whole group as the "Onondaga Salt group." The Salina beds occur in two belts in New York. The larger one extends in

nearly an east and west direction from Albany county through central and western New York to the Niagara river where it crosses into Ontario, Canada. The second area occurs in southeastern New York where there are two principal belts running roughly parallel. The beds of the two areas were deposited in different basins separated by a barrier in the Helderberg area which was effective only up to the time of deposition of the Cobleskill limestone. The western beds were deposited in a part of the interior or Mississippian sea, while the eastern deposits were laid down in an Atlantic basin. The strata of both the regions have the same color, showing deep red shales indicative of an arid climate. The conditions in the eastern basin apparently were not conducive to the deposition of salt and gypsum, but these beds need more exploration. The beds of the western area will be discussed first. Except for the upper waterlime member this group is made up of shales, chiefly red, green and gray, abundantly intercalated with gypsum beds and flaggy dolomites and reaching a total thickness of some thousand feet, more or less. All the workable gypsum deposits of the State are found within the Salina formation, and also the salt deposits.

The *Pittsford shale* (Clarke '03) constitutes the basal Salina series in the western area. It is a bed of black shale of inconsiderable thickness (ten to 20 feet), resting upon the Lockport dolomite, and was separated from the other shales on account of its fauna, mainly eurypterids. The name is derived from the type exposure at Pittsford, Monroe county, and here interbedded flaggy dolomite occurs. On Grand island in the Niagara river a shale of similar character occurs, but without eurypterids; and in Herkimer county the shales occur with

eurypterids. With the eurypterids is associated a sparse fauna of brachiopods, pelecypods, cephalopods and crustaceans. Among the eurypterids *Eurypterus pittsfordensis* and *Hughmilleria socialis* are the common forms. Of the other species, the brachiopod *Lingula semina*, the pelecypod *Pterinea poststriata* and the ostracod *Leperditia scalaris* are very common.

The *Vernon shale* (Clark '03) was named from the type locality in the town of Vernon, Oneida county. It is locally the heaviest member of the Salina series, and is practically all shale from bottom to top, with a thickness of about 500 feet in the middle of the belt near Syracuse and Auburn. East and west of this area it thins out, more rapidly to the east in which direction it dies out in Herkimer county where it is overlapped by the Camillus. The shales are mainly red and green, but there are gray, gypsiferous shales and thin, flaggy dolomites. The deep red color (due to ferric oxide) of the Vernon shales is characteristic, particularly in the eastern section; west of the Genesee river the shale becomes greenish (ferrous iron) with red layers. Thin layers of dolomite and scattered gypsum or anhydrite occurring near the top of the Vernon shales indicate drying up and concentration of the Salina sea sufficiently to cause precipitation of salts. Until about ten years ago the Vernon shales, as the Camillus, were believed practically barren of fossils. They were then found (1919) in the dumpings from the barge canal at Pittsford, N. Y. The Vernon fauna, as described (Ruedemann '21; Eaton '24), consists largely of pelecypods. It includes, besides, bryozoans, brachiopods, gastropods, cephalopods, crustaceans, eurypterids and worm borings. At best fossils are sparingly distributed in the rock, in fact are in gen-

eral very rare and in a fragmentary condition. Most of the fossils were obtained in the dark gray to black shale bands and the dolomitic slabs, but they also occur in the green shale. In certain layers the brachiopod *Camarotoechia litchfieldensis* is quite abundant; also the ostracod *Leperditia scalaris,* the crustacean *Ceratiocaris salina* and *Eurypterus pittsfordensis* are locally common. The species that are considered particularly characteristic are the cephalopod *Hexameroceras chadwicki,* the crustacean *Ceratiocaris salina* and the eurypterids *Hughmilleria phelpsae* and *Pterygotus vernonensis.*

The *Camillus shale* (Clarke '03) was named from Camillus in Onondaga county and includes, besides the shales, abundant gypsum and salt beds and flaggy dolomites. The salt-bearing strata are designated by the term *Syracuse salt* (Clarke '03), which includes the main salt layers and the salty shale and limestone associated with them. No sharp boundary exists between the salt-bearing strata and the rest of the Camillus, and it can only be determined from well records and shafts which reach the salt at a depth of 800 feet and more. In Wyoming and Livingston county salt beds occur with an aggregate thickness of 50 to 100 feet, and there are some beds of pure salt 40 to 80 feet thick. The Camillus shale is gray, drab, red or variegated and the dolomite is gray or drab. The total thickness of the whole series, including the gypsum and rock salt, is 450 to 500 feet in the central part of the belt in Onondaga and Cayuga counties and here the gypsum beds have a maximum thickness of 50 to 60 feet. Workable gypsum occurs at various levels below the Bertie waterlime. In the western area the high grade gypsum occurs 75 to 125 feet

below the Bertie, but in Madison and Onondaga counties the main deposits are directly under the Bertie. On the west these beds continue into Ontario; east of Madison county the Camillus shale thins rapidly, though it extends into Herkimer and Otsego counties. The *Brayman shale* which occurs in the east in Albany and Schoharie counties and has been correlated with the Camillus shales will be discussed below (page 341). The Camillus shales are practically barren of fossils. A pelecypod, *Ctenodonta salinensis,* has been described (Ruedemann '25) from these beds (Madison county).

The *Bertie waterlime* (Chapman '64) was named from the type section at Bertie, Canada, about six miles west of Buffalo. It is a series of drab or gray, argillaceous, more or less silicious dolomites which in years past were quarried on a wide scale for the manufacture of portland cement. In New York it occurs as far east as Otsego county where it has a thickness of ten feet or less. The maximum thickness of 60 feet is found in Ontario county, and it is 50 to 60 feet thick in Erie county. Besides the eurypterid fossils the Bertie waterlime is characterized by hopper-shaped casts and impressions which represent salt crystals derived from the salt originally deposited in the limestone and since dissolved away. The fauna of the Bertie waterlime derives its interest and importance from the prevailing eurypterid content. It is the upper horizon of abundant eurypterids, the Pittsford shale representing the lower. Characteristic eurypterids are *Eurypterus lacustris, E. remipes, Eusarcus scorpionis, Pterygotus buffaloensis* and *Dolichopterus macrochirus.* The number of species for the Bertie waterlime has been considerably increased in the past ten

years and includes, besides the eurypterids, marine fossils consisting of seaweeds, corals, graptolites, cystoids, bryozoans, brachiopods, pelecypods, gastropods, cephalopods and crustaceans (Ruedemann '25). It is not a typical marine fauna, however, and many of the forms studied were represented by only a few examples. The scarcity of marine shells is believed to be due to early dissolution in the dolomitic mud. The character of the fauna, with a number of strange forms, and the relation of the waterlime to the overlying "Bullhead" (Akron dolomite) are an indication of the true situation. The Akron dolomite is the western continuation of the Cobleskill limestone or coral facies and the close connection between the Bertie waterlime and this suggests that the Bertie was deposited in a lagoon behind coral reefs (farther to the south in Bertie time), and that a sinking of the land resulted in an invasion of the sea and a freshening of the waters in which the barren Camillus shale was deposited (Ruedemann). All the fossils of the Bertie, including the eurypterids, have been found in the uppermost Bertie beds as one approaches the purely marine conditions of the Cobleskill.

The *Brayman shale* (Grabau '06) was named from its occurrence at Braymanville in Schoharie county. It is a green and gray, pyritiferous shale which lies beneath the Cobleskill in Schoharie county and continues into Albany county. The maximum thickness in the Schoharie area is 40 feet, less than three feet are found in the Indian Ladder region of Albany county and a short distance below this, at New Salem, the thickness has dwindled to ten inches. Farther south again (Feura Bush and Bethlehem quarries) it thickens to nine feet or

more. As stated above (p. 340) the Brayman shale has been considered of Salina age and correlated with the Camillus. Recently the conclusion has been reached (Ruedemann '12, '30; Ulrich) that this shale is probably a residual soil of the Ordovician which represents the hiatus between the Frankfort or the Indian Ladder beds (Ordovician) and the Cobleskill or Rondout limestone above (Silurian). It is not directly attachable to any of the Ordovician formations, but overlaps three of them: the Frankfort shales to the west, the Schenectady beds in the Schoharie region and the Indian Ladder beds farther east.

The Salina beds of southeastern New York begin with the High Falls shale. The Shawangunk conglomerate formerly considered the basal formation of the Salina in the eastern basin (see p. 333) is now believed to be of Medina age by some, by others at least as young as Clinton. The *High Falls shales* (Hartnagel '05) are red shales overlying the Shawangunk in the Kingston-Port Jervis section, with a thickness of 80 to 90 feet. They are pyritic and in places grade up into the sandstone. The name is based upon the occurrence at High Falls, Ulster county. Above the shales in Ulster county is a light colored, quartzite, the *Binnewater sandstone* (Hartnagel '05), named from its occurrence at Binnewater, seven miles southwest of Kingston, which has a thickness of 32 to 135 feet. South of High Falls the quartzite becomes more calcareous and of a shaly nature. The term *Longwood shales* (Darton '94), from the Longwood valley in New Jersey, is applied to the red shales above the Shawangunk in Orange county and New Jersey. They are considered, in part or wholly, the stratigraphic

equivalent of the High Falls shale and perhaps the Binnewater sandstone also. This shale bed has a thickness of 150 feet. The *Wilbur limestone* (Hartnagel '05) and the *Rosendale waterlime* (Hartnagel '05) probably together represent the Bertie waterlime farther west. The Wilbur limestone overlies the Binnewater sandstone or, when this is absent, the Ordovician shales. It has its best exposure in the Rondout valley and receives its name from the town of Wilbur on the Rondout creek, a mile south of Kingston. This is a fossiliferous limestone which takes the place of the Rosendale waterlime in passing southward toward the Port Jervis region (Hartnagel). The Rosendale waterlime underlies the Cobleskill limestone in Ulster county and in part, at least, is the equivalent of the Bertie waterlime, formed in a separate basin. There are no euryterids, however, in this waterlime. The name was taken from the village of Rosendale, eight miles southwest of Kingston. South of High Falls it changes into a fossiliferous limestone. The formation has a thickness of 14 feet and was formerly quarried for cement.

The *Cobleskill limestone* (Hartnagel '03) is named from its exposure on the Cobleskill, Schoharie county, and was known as the "Coralline limestone" on account of its great abundance of corals. It is a thin formation, having its greatest thickness of seven to 30 feet in east central New York and a thickness of five to eight feet in western New York. It is the lowest of the many limestone formations of the Schoharie area. The Cobleskill limestone is a typical coral facies and, while it does not show the reef character, it has the reef species. To

the dolomitic phase in Erie county, known locally as the "Bullhead" limestone, the name *Akron dolomite* (Sherzer and Grabau '09) has been given from the occurence at the village of Akron. The Akron dolomite is a little later faunal development than the Cobleskill (Hartnagel). Among the characteristic fossils of the Cobleskill are the corals *Halysites catenulatus, Favosites niagarensis, Diplophyllum coralliferum* and the cup coral *Enterolasma caliculum,* and species of *Stromatoporas* (hydrocorallines). The coral *Cyathophyllum hydraulicum* and the brachiopod *Spirifer eriensis* are the characteristic fossils of the Akron phase. In the Schoharie area and westward the pelecypod *Ilionia sinuata* is characteristic and the presence of the trilobite *Lichas* (*Corydocephalus*) *ptyonurus* always identifies the Cobleskill.

The *Rondout waterlime* (Clarke and Schuchert '99) received its name from the fine development in the extensive quarries and cement mines in the vicinity of Rondout. The same beds have also furnished cement in the Schoharie area. This drab-colored waterlime, formerly known as the "Salina waterlime," extends as far west as Seneca county where it is overlapped by the Onondaga. In the intervening area it lies between the Cobleskill and the Manlius. The average maximum thickness is 40 feet, but in the Cobleskill region it thickens to 60 feet, the lower six feet of which are mined for cement in Howe's Cave. In certain areas (as Rondout) the surface of some beds is characterized by mud crack structures, mostly of pentagonal form, indicating exposure of the lime mud at times to the drying influence of the sun. The coral *Favosites helderbergiae* var. *precedens* has

been found in these beds at Howe's Cave in the Cobleskill area, having passed up from the underlying Cobleskill limestone.

The *Manlius limestone* (Clarke and Schuchert '99) was named from the exposure at Manlius, N. Y., and includes near the top in Onondaga county two thin beds of waterlime which are used for cement. This formation has been known as the *"Tentaculite limestone"* (Gebhard, Mather and others) from the abundant occurrence of *Tentaculites gyracanthus,* and the "Waterlime group of Manlius" (Vanuxem '39). It extends under the Coeymans limestone (Lower Devonian) as far west as Onondaga county, and west of this is overlain by the Oriskany or Onondaga to the limit of its extent in Seneca county. The only occurrence of the Manlius on the east side of the Hudson valley is an outlying area at Becraft mountain where it is being quarried for cement. It is also quarried for road metal in a number of localities. The Manlius, typically, is a thin-bedded, dark blue limestone of fairly pure composition. The layers are one to three inches or more thick, and are especially thin in the lower part with alternating light and dark beds ("ribbon-limestone"). The slabs of this limestone break with a ringing sound, and the rock when weathered has a characteristic light color. Because of the hardness of the rock it tends to form a distinct vertical cliff by itself or together with the Coeymans limestone above (figures 51, 52). The Manlius beds have a maximum thickness of 150 feet, more or less, in the central part of the State, but in the Helderberg and Schoharie areas there is a thickness of about 50 or 55 feet. In the Helderberg area

(Indian Ladder) there are about 14½ feet of so-called transitional beds below the Coeymans limestone which are included in the measurement. The Manlius limestone shows features, such as mud cracks and faint ripple marks, that clearly indicate tide-flat conditions. This limestone is also characterized in the upper part by heavy *Stromatopora beds* (*Syringostoma barretti*). These reefs, together with the mud cracks, ripple marks etc. suggest that the Manlius limestone is a lagoon deposit on tide flats formed between and behind the coral reefs (Ruedemann '30). The fauna of the Manlius is a meager one. The characteristic fossils are the pteropod *Tentaculites gyracanthus* which occurs in great abundance in certain layers, the ostracod *Leperditia alta,* and the brachiopod *Spirifer vanuxemi.* In the transition beds the small brachiopods *Stropheodonta varistriata* and *Camarotoechia semiplicata* are found.

The Lower Helderberg beds in the early days of the Survey were classed with the Silurian. Later the Siluro-Devonian boundary was changed (Clarke) and the Lower Helderberg limestones with the exception of the Manlius were placed in the Lower Devonian. The Manlius, because of the rather Silurian aspect of its meager fauna was left in the Silurian and since then has been the subject of much discussion as to its age. Some, following Clarke, class the entire Manlius as Silurian, others would place it with the Devonian and a third group place the dividing line within the Manlius. According to the last view the lower portion of Manlius exposed in the Helderberg-Schoharie area represents the lower beds and is the typical Manlius, Silurian in age. The

upper two to 15 feet of limestone in the Schoharie and Indian Ladder areas, long distinguished as "transitional beds," and the so-called Manlius beds exposed in the "Old Glory Hole" at Rondout are Upper Manilus and Devonian (Keyser of Maryland and Virginia) in age. In the Rondout and Rosendale areas the lower or typical Manlius is either entirely wanting or very thin. South of Rondout no Manlius (that is, the lower beds) occurs. The Upper Manlius beds of western New York are also considered as Keyser and Devonian (Ulrich). So far as the Manlius of the eastern Helderberg region is concerned a distinct, irregular unconformity has been observed between the Manlius and Coeymans in the Indian Ladder region and at Catskill where Manlius pebbles were found in the basal layers of the Coeymans (Chadwick).

Characteristic areas which together give a complete section of the Silurian beds of New York are the Niagara-Rochester areas and the Kingston area. In the Niagara river area, Lewiston to Buffalo, is a most typical as well as a classic section of the North American Silurian. In the mouth of the gorge near Lewiston the brick-red Queenston shales are capped by the white quartzose Whirlpool sandstone, above which are the red shales and sandstones of the typical Medina beds (Albion sandstone) terminated by a bed of white quartzite, the Thorold quartzite, now regarded as the basal Clinton. This quartzite is followed by a thin shale and two limestone formations representing the Clinton beds and with the characteristic Clinton fossils. Then comes the Rochester shale, the uppermost member of the Clinton

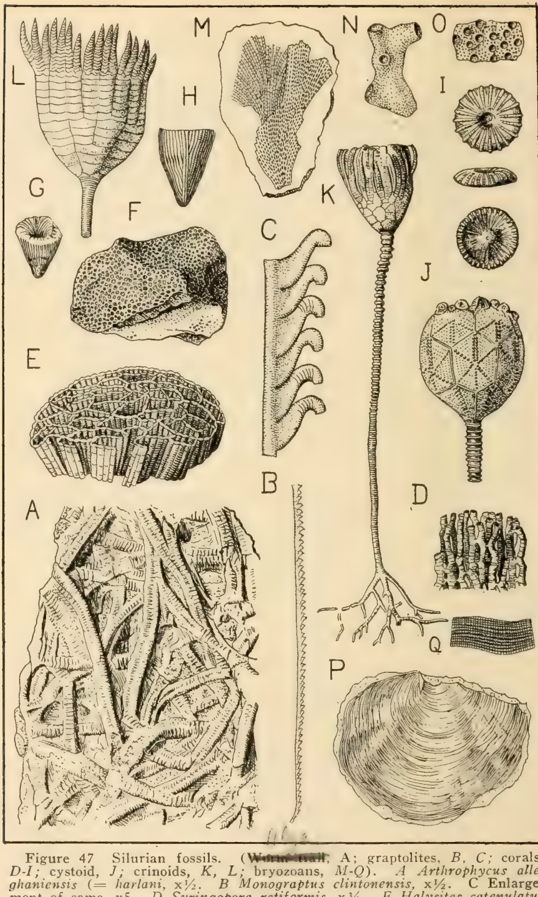


Figure 47 Silurian fossils. ([redacted], A; graptolites, *B, C;* corals, *D-I;* cystoid, *J;* crinoids, *K, L;* bryozoans, *M-Q*). *A Arthrophycus alleghaniensis* (= *harlani,* x½. *B Monograptus clintonensis,* x½. C Enlargement of same, x5. *D Syringopora retiformis,* x¾. *E Halysites catenulatus* (= *catenularia*), x½. *F Favosites niagarensis,* x½. *G, H Streptelasma* (*Enterolasma*) *caliculum,* x¾. *I Palaeocyclus rotuloides,* x1. *J Caryocrinus ornatus,* x¾. *K Eucalyptocrinus crassus,* x½. *L Ichthyocrinus laevis,* x¾. *M Fenestella elegans,* x½. *N, O Callopora elegantula,* x¾, with enlargement. *P, Q Lichenalia concentrica,* x½, with enlargement of surface.

formation, and the cliff is terminated by the Lockport dolomite. These beds are all more or less richly fossiliferous. A similar succession of formations is seen in the walls of the gorge of the Genesee river near Rochester (figure 46), and east of here the Salina beds appear. In the Niagara river area the Salina beds are covered by drift but are known from borings. In a cement quarry in North Buffalo the Bertie waterlime is at the base and is followed by the Cobleskill (Akron) dolomite, above which the Onondaga limestone lies unconformably.

In the section in the Kingston area the Cobleskill limestone lies unconformably upon the Ordovician shales, followed by the Rondout waterlime and the Manlius, which is succeeded by the coarser-grained Coeymans (Devonian). South of Kingston in the Rosendale area the series of formations below the Cobleskill appear. Immediately below is the Rosendale waterlime and under this the Binnewater sandstone and High Falls shale. Beneath this series lies the Shawangunk conglomerate (of Clinton age) which thickens southward and from Rosendale toward the Helderberg region shows a northward overlap.

The fossils. Characteristic fossils of the Silurian system of rocks are illustrated in figures 47–49. They are as follows:

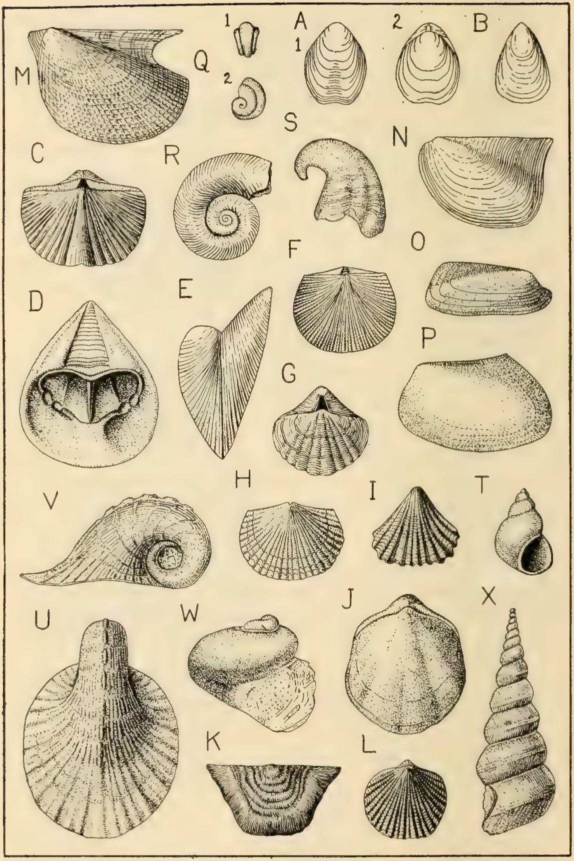


Figure 48 Silurian fossils. (Brachiopods, *A-L;* pelecypods, *M-P;* gastropods, *Q-X*). *A* 1, 2 *Whitfieldella sulcata*, x¾. *B Lingula cuneata*, x1. *C Spirifer niagarensis*. *D, E Monomerella noveboracum;* internal view of valve and side view of exterior, x¾. *F Schuchertella interstriata*, x½. *G Spirifer vanuxemi*, x1½. *H Orthis flabellites*, x¾. *I Rhynchotreta cuneata* var. *americana*, x¾. *J Pentamerus oblongus*, x½. *K Leptaena rhomboidalis*, x½ (Niagaran type). *L Atrypa nodostriata*, x¾. *M Pterinea emacerata*, x¾. *N Liopteria* (?) *subplana*, x¾. *O Orthodesma curtum*, x¾. *P Modiolopsis primigenia*, x1. *Q* 1, 2 *Bucanella trilobata*, x1. *R Euomphalus fairchildi*, x½. *S Platyceras niagarense*, x½. *T Holopea pervetusta*, x¾. *U, V Tremanotus alpheus* (*Trematonotus* C & R), x½. *W Diaphorostoma niagarense*, x¾. *X Coelidium macrospira*, x½.

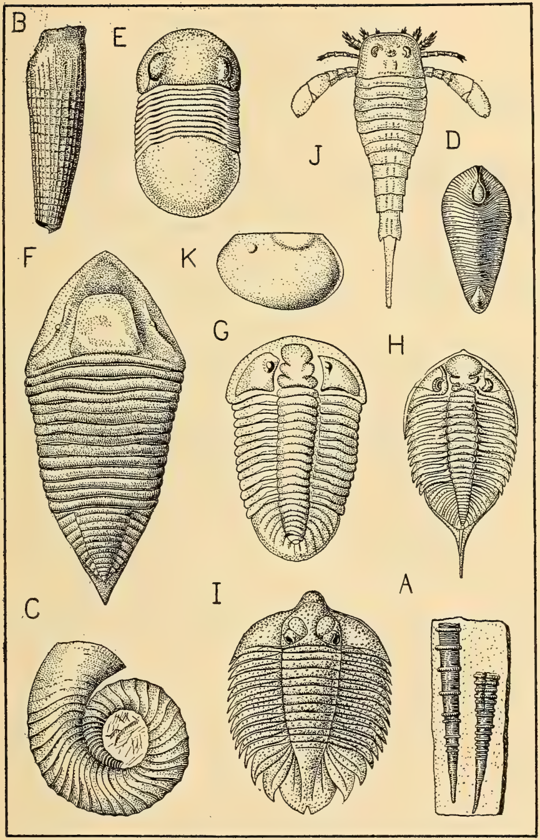


Figure 49 Silurian fossils. (Pteropod, *A;* cephalopods, *B-D;* trilobites, *E-I;* eurypterid, *J;* ostracod, *K*). *A Tentaculites gyracanthus,* x2. *B Kionoceras darwini,* x½. *C Trochoceras costatum,* x½. *D Phragmoceras parvum,* x½. *E Bumastus (Illaenus) ioxus,* x⅓. *F. Homalonotus delphinocephalus,* x⅓. *G Calymene niagarensis,* x1. *H Dalmanites limulurus,* x⅓. *I Arctinurus (Lichas) boltoni,* x½. *J Eurypterus remipes,* x¼. *K Leperditia scalaris,* x2.

Silurian Fossils

GRAPTOLITES

Monograptus clintonensis (Clint.*)

CORALS

Enterolasma caliculum (Niag.)
Favosites niagarensis (Niag.)
Halysites catenulatus (Sil; Niag., etc.)
Palaeocyclus rotuloides (Up. Clint., Niag., etc.)
Syringopora retiformis (Niag.)

BRYOZOANS

Fenestella elegans (Roch. sh.)
Hallopora elegantula (Niag.)
Lichenalia concentrica (Roch. sh.)

BRACHIOPODS

Atrypa nodostriata (Clint., Lock.)
Leptaena rhomboidalis (Ord.-Miss.)
Lingula cuneata (Med.)
Monomorella noveboracum (Glph)
Orthis flabellites (Niag.)
Pentamerus oblongus (Niag.)
Rhynchotreta cuneata americana (Lock.)
Schuchertella interstriata (Cobl.)
Spirifer niagarensis (Niag.)
Spirifer vanuxemi (Man.)
Whitfieldella sulcata (Cobl., Man.)

PELECYPODS

Leiopteria subplana (Roch.-Glph)
Modiolopsis primigenia (Med.)
Orthodesma curtum (Clint.)
Pterinea emacerata (Clint., Lock.)

GASTROPODS

Bucanella trilobata (Med.-Lock.)
Coelidium macrospira (Glph)
Diaphorostoma niagarense (Niag.)
Euomphalus fairchildi (Glph)
Holopea pervetusta (Man.)
Platyceras niagarense (Niag.)
Trematonotus alpheus (Glph)

PTEROPODS

Tentaculites gyracanthus (Man.)

CEPHALOPODS

Kionoceras darwini (Glph)
Phragmoceras parvum (Glph)
Trochoceras costatum (Glph)

CYSTOIDS, CRINOIDS

Caryocrinus ornatus (Roch. sh.)
Eucalyptocrinus crassus (Niag. of Ohio, Ind., Ill.)
Ichthyocrinus laevis (Roch. sh.)

TRILOBITES

Arctinurus (Lichas) boltoni (Roch.-sh.)
Bumastus (Illaenus) ioxus (Niag.)
Calymene niagarensis (Niag.)
Dalmanites limulurus (Niag.)
Homalonotus delphinocephalus (Niag.)

OSTRACODS

Leperditia scalaris (Sal., Cobl.)

EURYPTERID

Eurypterus remipes (Bertie w.l.)

WORM TRAIL

Arthrophycus alleghaniensis (Med.)

* Clint. = Clinton; Cobl. = Cobleskill; Glph. = Guelph; Lock. = Lockport; Man. = Manlius; Med. = Medina; Miss. = Mississippian; Niag. = Niagaran; Ord. = Ordovician; Roch. = Rochester; Sal. = Salina; Sil. = Silurian.

Literature. For the general discussion of the system are recommended the textbooks cited under the previous chapters and Grabau ('09), Schuchert ('14) and Ulrich ('11).

For a general account and many references to New York literature, see Miller ('24). Other New York State publications on the various formations are: Clarke ('99, '07), Clarke and Luther ('05), Clarke and Ruedemann ('03, '12), Eaton ('23), Grabau ('01, '06), Hartnagel ('03, '05, '07a, b, c, '12), Ruedemann ('16, '21, '25, '30), Shimer ('05), Smith ('29), Ulrich and Schuchert ('02) and Van Ingen and Clark ('03). For the Clinton iron ore, salt and gypsum deposits consult the following New York State publications: Alling ('28), Newland ('29), Newland and Hartnagel ('08). References other than those in the Museum publications are: Chadwick ('18), Grabau ('13), Kindle and Taylor ('13), Prosser ('07), Schuchert ('03a, b, '14, '16) Sherzer and Grabau ('09), Ulrich ('13) and Ulrich and Bassler ('23a, b).

Devonian Period

The beds beneath the "Carboniferous" were not determined before 1833. Beneath the coal-bearing strata was a series of red sandstones and marls, and above was a similar series. They were termed the Old and New Red Sandstone respectively. The Old Red Sandstone is typically developed in Scotland and was made widely known through the work of Hugh Miller, but it was not regarded as a distinct system. Sedgwick and Murchison in their work in Devon and Cornwall found distinctive fossils in rocks occurring between the Silurian and Carboniferous which made it apparent that they and the sim-

ilarly placed Old Red Sandstone farther north belonged to a new system. To these rocks in 1837 the name Devonian was given from the exposures in Devonshire which then became the type section, though a far better section of Devonian rocks is found in western Germany and adjoining areas in Belgium. As with the preceding systems, North America again furnishes the most complete record. The rocks here are preserved over wide areas and, unlike the type section, are for the most part little disturbed. New York State again furnished the type section for the American Devonian and hence, in a way for the world. Other important exposures occur in Appalachian areas and in Michigan, the latter extending into Wisconsin and Iowa and also into Ohio, Indiana and Ontario. In certain areas as in parts of the western half of the Middle Appalachian region the transition from the Silurian to the Devonian is so gradual that the boundary between the two systems has been long in doubt. Until recently the Helderbergian formations were placed in the Silurian and the Oriskanian at one time was even included in the same system. Helderbergian limestones, with some interruptions, occur from southwestern Virginia to Albany, N. Y. along the Appalachian line.

Geology. At the close of the Silurian or the beginning of the Devonian there was an almost complete emergence of the continent of North America, and at no time during the Lower Devonian epoch was more than ten per cent. of the continent submerged. The continent of Appalachia at this time was extensive and probably a broad mountainous upland with its eastern boundary extended perhaps 50 miles or more beyond the present continental shelf. The character of the sediments indicates

that the land of Appalachia probably never reached Alpine heights but was slowly raised as the Appalachian trough sank. In the beginning of the Devonian (Helderbergian epoch) the seas were small and shifting. The epicontinental waters were confined almost entirely to the Appalachian trough and the Cordilleran area. The Appalachian trough opened to the Atlantic on the northeast (Gaspé region) and the fauna from that province entered its waters. Erosion occurred over the interior of North America. As Lower Devonian time continued the sea in the Appalachian trough deepened and enlarged and a subsidence in the south permitted the sea to spread over western Tennessee into Missouri, southern Illinois and Oklahoma. In the Gaspé area about 1500 feet of limestones represent the Lower Devonian (Helderbergian and Oriskanian series). The Helderbergian sea also covered northern and southern New Brunswick, northern Nova Scotia, northern Maine and part of its coasts and occupied the New England troughs. In the west Helderbergian formations have only been found in the Nevada trough, and Helderbergian fossils are found in the north on the shore of Kennedy channel (Lat. 80° N.).

The sea withdrew from part of the Appalachian trough at the end of the Helderbergian epoch and in the erosion that followed much of the Helderberg deposits were removed in some areas. The lime sediments from this erosion, during the retreat of the sea in late Helderbergian, locally accumulated in depressions and formed a detrital lime rock (the Port Ewen beds). At this same time deposition continued in the northern area of the trough forming the thick Lower Devonian series at Gaspé. During the period of withdrawal of the sea the eroded land surface was accumulating sand from various sources so

that when the Lower Devonian Oriskany sea flooded the trough again and spread westward over this eroded surface these sands were reworked by the waves and deposited as the Oriskany sandstone, which is very fossiliferous in places. In Pennsylvania it is a thick deposit of very pure quartz-sand, but in some places it is no more than a thin layer of quartz grains. At the end of Oriskany deposition the Cumberland area of the Appalachian trough was elevated and in eastern New York we have only the coarse sands and grits of a mud delta constituting the Esopus formation (Oriskanian). Submergence became pronouncedly positive in late Lower Devonian (late Oriskanian) time and continued to the maximum flooding of the continent in late Middle Devonian (Hamilton) time.

The great submergence of the Middle Devonian in North America had its counterpart in Europe, Asia, Australia and South America, and was one of the greatest floodings in geologic history, exceeded later only by the great submergence of the Cretaceous. The interior sea was again established and in it was accumulated the Onondaga limestone which with its wealth of corals and brachiopods indicates a warm, clear sea surrounded by lowlands, and it must have been of long duration. The warm waters brought many coral species and an abundance of corals first from the North Atlantic and Gulf of Mexico and later from the Arctic sea that advanced southward. These corals built extensive reefs in the limestone deposits, such as the famous occurrence at the Falls of the Ohio, Louisville, Ky. The Onondaga limestone stretches from the Hudson river across New York to Michigan and it also extends into Indiana, Illinois and Kentucky around what were perhaps islands of the Cin-

cinnati anticline. In the west the Cordilleran sea occupied much of the Great Basin area, probably connecting on the north with the advancing Arctic sea. As Middle Devonian time continued there was an alteration of conditions in the northeastern part of the continent bringing about a change in the character of deposits. The land here was elevated resulting in the rejuvenation of the streams which brought into the sea large quantities of mud and silt, (Marcellus black shales, Hamilton shales and flags), checking the deposition of limestone. These deposits are thick in the east, and grow thinner westward. The accumulation of limestone continued in the Mississippi valley and even in New York State thin limestone beds occur at intervals in the thick mass of Hamilton shales. The uplift converted the Gaspé area into a coastal lagoon in which swift streams deposited great masses of sand, these continental deposits containing fossils of land plants and giving indications of occasional invasions of the sea. The deposits in New Brunswick and Nova Scotia are also sandstones and shales. Part of the Middle Appalachian area that was uplifted at the end of the Lower Devonian was now occupied by an extension of the interior sea (western Maryland and adjoining parts of Virginia). At the close of the Middle Devonian there was a further shrinking of the seas coincident with the further rise of Appalachia and the rejuvenated streams continued to build great deltas in the northern part of the Appalachian trough, (as the Ashokan bluestone delta in New York). The seaways from the North Atlantic through Acadia connecting the interior sea with the St Lawrence trough were forever destroyed by the Acadian Disturbance which resulted in the elevation and folding of the Acadian land throughout

New England and the Maritime Provinces of Canada. This disturbance started in the Middle Devonian but continued even to the end of Devonian time. Meanwhile through the later Middle Devonian the Cordilleran sea was spreading eastward bringing in its waters immigrants from Asia by way of Alaska. The Middle and Upper Devonian beds are separated by an erosion interval indicating the withdrawal of the sea at the end of Hamilton time.

During the Upper Devonian the continental seas were gradually withdrawn, first from the southern Mississippi valley area and then from the interior and the Cordilleran areas, until at the end of the Devonian there was a practically complete emergence of North America. Here and there in the Mississippi valley the Upper Devonian overlaps older rocks where the Lower and Middle Devonian are absent. The Tully limestone marking the base of the Upper Devonian is a locally developed limestone in New York State which carries the characteristic brachiopod *Hypothyris cuboides* (*Hypothyridina venustula*) occurring also in the *Cuboides zone* in the Rhenish section of Europe. Following the close of the Middle Devonian and at the beginning of the Upper Devonian, parts of Tennessee, Alabama, Kentucky, northeastern Arkansas, Indiana and western Michigan were submerged and received deposits of black fissile shale that contains a typical Genesee shale fauna. In all the mentioned areas this is followed by the Ohio or Chattanooga shale now generally conceded to be of early Mississippian age. The Genesee in the east is another mass of black shale which increases in thickness from Lake Erie to Pennsylvania. It is a bituminous black shale with few fossils. These black shales are followed by shales largely arenaceous

and constituting the Portage beds which in western New York and Virginia carry a characteristic fauna (Naples fauna) of goniatites and pelecypods which has little in common with the Hamilton but is well marked in many parts of the world, having been traced by way of our northwest through Manitoba into Siberia and thence through Russia into Westphalia (Germany). In New York it was an alien fauna. To the eastward it is replaced by the Ithaca fauna of Hamilton aspect. From Chenango county eastward above the Ithaca beds are nonmarine beds of red and gray or greenish shales carrying plant remains at intervals (Oneonta series) and capped by a thick mass of sandstones, chiefly red beds (Catskill beds) which represent a facies of the Upper Devonian, beginning in early Portage time and continuing through the Upper Devonian and even into early Mississippian in Pennsylvania. These beds contain at some horizons fresh or brackish water clams. They are believed to have been deposited in a long and narrow estuary running from eastern New York into Pennsylvania where they have a thickness of over 3000 feet. To the west occur the marine Chemung beds, a great mass of sandstones and conglomerates which reach their maximum thickness in Pennsylvania (3500 feet in central part) and thin greatly westward. They rest upon the Portage (Naples) beds in the western part of New York State, the Ithaca beds in the central part and the Oneonta in the eastern. In New York State the Upper Devonian beds of the east are mainly continental, becoming increasingly red toward the top, while in the west they are marine with no red beds and in between intermediate conditions are seen. The red Catskill beds spread west and progressively replace the marine Chemung beds. The subdivisions of the

Western Devonian can seldom be correlated with those in the East, as such a different succession of physical events are indicated.

The Devonian period had a little more than half the duration of Ordovician time and closed with almost complete emergence of the continent. As we have seen, besides in New York State, Devonian rocks outcrop in the Michigan area and extend into Wisconsin and Iowa, Ohio, Indiana and Ontario, Canada. Occurrences are also found in Oklahoma, Missouri and western Tennessee and Kentucky. Along the line of the Appalachians Devonian rocks have been traced, with interruptions, from southwestern Virginia to Albany, N. Y. In the St Lawrence region deep deposits occur in the Gaspé area. Northern Nova Scotia and northern Maine also have these rocks. In the west Devonian strata, often in considerable thickness, occur in the Rocky mountains and in the Canadian northwest; Devonian beds occur even far north on the shore of Kennedy channel, 80° N. latitude. Devonian rocks in New York state have a total thickness between 8000 and 9000 feet, the Catskill mountains along the Hudson representing the most impressive single accumulation of Devonian deposits in the United States. In the northern Appalachians the deposits are mostly shales and fine-grained sandstones and here are found the thickest series of Devonian beds in the country representing the longest sequence. Pennsylvanian deposits show the greatest thickness, 13,000 feet of shales and sandstones which become less marine, coarser and redder toward the top. Here the Lower Devonian has a thickness of about 250 to 400+ feet, the Middle Devonian of about 1400 to 2750 feet, the

Upper Devonian of about 5800 to 9700 feet (mostly red shales, coarse sandstones and conglomerates). In Maryland the Lower Devonian has a greater thickness, the Middle and Upper Devonian less. Devonian deposits in the interior are very thin compared to those in the east. About 50 feet of Middle Devonian limestone and shales are represented at Louisville, Ky. In the southern Mississippian valley and Oklahoma the deposits represent, for the most part, Lower and early Middle Devonian and here also the deposits are thin (less than 250 feet). Western Ontario, Canada, shows a thickness of something over 500 feet of deposits, mostly shales, but the thickest accumulations in the median part of North America, thicker than in Ontario, are found in Michigan, particularly about Alpena, where they represent the Middle and Upper Devonian. Devonian deposits in the Cordilleran area are mostly limestones and in Nevada have a thickness of 4000 to 8000 feet (limestones and calcareous shales), though most sections in this area are comparatively thin in the United States. In the MacKensie valley about 1000 feet (nearly one-half limestone) were deposited and exposures show about 600 feet of limestone in southeastern Alaska.

Throughout the Devonian and especially in the Upper Devonian igneous activity occurred in the New England states and the Maritime Provinces of Canada in connection with the Acadian Disturbance which was perhaps a forerunner of the later revolution which formed the Appalachian mountains. The volcanic cones are eroded away and only the deeper seated volcanic rocks remain. Mount Royal at Montreal is one of these. Besides the volcanic extrusions, igneous intrusions (grani-

tic) took place, and such intrusions are found in many places throughout New Brunswick, in Nova Scotia and southern Quebec. Igneous intrusions of Devonian age also occur in Maine and possibly Vermont and New Hampshire. Thin coal beds of very local distribution occasionally occur in the Upper Devonian but are not of commercial value. They are an indication of the presence of swampy areas abounding in plants. Petroleum is found quite extensively in the Upper Devonian of western New York and Pennsylvania in the Chemung, at or near the base. A much smaller amount occurs in the Portage, rarely in the Onondaga of New York. In Canada the production is entirely from the Onondaga.

Life. Four faunal provinces are represented in the Devonian: the North Atlantic, the Southern or Gulf, the Pacific and the Arctic. In the Appalachian and Acadian areas the North Atlantic waters were dominant in the Lower Devonian and here faunal relations are shown with the life of northern Europe (Coblenzian fauna) indicating the existence of a land bridge across the North Atlantic affording the necessary conditions for the migration of the shoal-water animals. Later in the period the faunal assemblages were those of the interior sea. The Arctic sea with its fauna spread southward and near the close of the Middle Devonian the Cordilleran sea with its northern Pacific or Euro-Asiatic fauna had spread eastward. By Upper Devonian times the seaway through the Acadian land in the northeast was closed. In almost all seas the faunas had the Euro-Asiatic aspect.

The animal life of the Devonian has the same general aspect as that of the Silurian. There are many changes

in genera, but an almost total change in species. *Sponges* were a conspicuous element of the Devonian fauna and particularly deserving of mention are the glass sponges (Dictyospongidae) characteristic of the Upper Devonian (Chemung) of certain areas. In sandstones of this age in south-central New York at least five colonies of these sponges have been found, comprising nearly one hundred species. *Corals* have expanded and multiplied enormously both in size and numbers. They are known from Louisville, Kentucky, where the famous coral reef is located, north into Alaska. Corals are not equally distributed in the different formations, but usually are common in the limestones and rare in the shales and sandstones since they do not thrive in muddy waters. Most of the Silurian genera persist. The corals are represented by cup corals (*Heliophyllum*), honey-comb corals (*Favosites*), organ pipe corals (*Syringopora*), etc. *Phillipsastraea* and *Acervularia* are also among the reef builders. *Graptolites* which were so characteristic of certain Ordovician deposits and much less common in the Silurian became almost extinct in the Devonian. A few simple species lived in the Lower Devonian. *Cystoids* are rarer than in the Silurian, in fact are on the point of extinction. *Blastoids* are locally abundant in a few places, but they do not reach their culmination until the Mississippian, after which they occur sparsely and disappear with the Paleozoic. *Crinoids* have increased greatly in numbers and variety, and contributed largely to the building up of calcareous deposits. Characteristic genera are *Cupressocrinus, Platycrinus, Actinocrinus, Dolatocrinus, Edriocrinus* etc. *Starfishes* (*Devonaster*) were at times also abundant and had already acquired the

present mode of feeding. *Bryozoans* were locally abundant. The Devonian deposits were full of *brachiopods.* In no other period have they been more abundant in both individuals and species, and there are many characteristic forms: *Gypidula, Rensselaeria, Stringocephalus, Eatonia, Tropidoleptus, Meristella, Athyris, Spirifer* etc., the long-hinged *Spirifers* being especially abundant and characteristic. *Pelecypods* also were abundant where there were favorable conditions, muddy bottoms etc. Among the genera represented are *Aviculopecten, Pterinea, Actinodesma, Goniophora, Modiomorpha, Orthonota, Grammysia, Cypricardella* etc. *Gastropods* were not uncommon but not as abundant as the pelecypods. Among the genera represented are *Platyceras* (including spiny forms), *Diaphorostoma, Loxonema, Lophospira, Euomphalus, Bucanopsis, Euryzone, Phragmostoma, Ptomatis* etc. A minute pteropod, *Styliolina,* is very abundant, forming limestone masses in the Upper Devonian. Among the *cephalopods,* straight *Orthoceras* types and coiled forms with simple sutures (*Phragmoceras, Gomphoceras, Cyrtoceras*) continued. The great abundance of nautiloid types of the Silurian had diminished in the Devonian. The ammonoid division of the cephalopods of which *Goniatites* is a common form comes in for the first time in the Upper Devonian. These forms were destined to attain extraordinary development in the Mezozoic but the sutures in the Devonian forms are only angled and lobes are much less complex than in the later ones. Another genus, *Clymenia,* was far more abundant in Europe than in America. There also occurred a form, *Bactrites,* with a straight shell, like *Orthoceras,* but which showed its ammonoid nature in its complex

suture lines. *Trilobites* had already begun to decline in the Silurian and this decline is more marked in the Devonian. They are far from rare, however, but lack the variety they previously had. There are new species of Silurian genera, *Phacops, Homalonotus* (*Dipleura*) *Lichas, Odontocephalus* etc. being among the commonest genera. One of the largest and most striking forms characteristic of the Devonian is the genus *Terataspis*. Other crustaceans have had notable development in this period, among them the *phyllocarids* abundant in the Middle and Upper Devonian. *Eurypterids* attained their greatest size during Devonian time, and some of them were actually gigantic reaching lengths of six to eight feet. Genera represented (*Eurypterus, Stylonurus* and *Pterygotus*) are the same as in the Silurian. The vertebrates are one of the most characteristic features of the Devonian and because of the great development of the fishes this period has been termed the "Age of Fishes." Fishlike *ostracoderms* are present (*Cephalaspis, Pterichthys, Bothriolepis* etc.). True fishes are present in great variety. Sharks are represented by such forms as *Cladoselache*. *Lung fishes* (*Dipterus, Scaumenacia*) are an important element in this fauna; *armored fishes* or *arthrodires* are represented by such forms as *Coccosteus* and *Dinichthys*. The *ganoids* (*Holoptychius, Eusthenopteron*) are the most advanced fishes of the period. While the fish fauna is rich and varied and each group has many representatives, the forms are mostly very strange and curious and of a primitive character. Our modern bony fishes (teleosts) are entirely absent. *Amphibians*, representing the lowest air-breath-

ing vertebrates, are known (through footprints) from the Upper Devonian.

For the first time we may speak of the *flora* of a period, though not perhaps until Upper Devonian is the term strictly applicable. The vegetation of the Devonian was characteristic. There is evidence that the land was clothed with a vegetation which in the latter part of the period was quite varied. Here we have the oldest forests known and in them green fernlike plants, tree ferns, seed ferns, rushes, lycopods or giant club mosses, and primitive evergreens or gymnosperms with woody trunks. The seed ferns and club mosses have been estimated to have reached heights of 25 to 40 feet. The fernlike forms are so characteristic of the Devonian flora, and one of the forms (*Archaeopteris*) so common that the flora has been called the *Archaeopteris flora* and the time the *Age of Archaeopteris.* This flora had a wide distribution through eastern North America, extending into the Arctic regions, Spitzbergen and northwestern Europe.

Climate. All evidence, as in previous times, points to a uniformly warm though semiarid climate. The wide distribution of the flora is evidence of equable climates. The trees grew in wet places in valleys and in swampy areas and were without rings of growth, indicating an absence of seasonal changes. The profusion of corals and wide distribution of coral reefs is another proof of a warm climate. The red deposits of the Upper Devonian are indicative of a more or less semiarid condition; deserts existed in some places, just as in others there were extensive swamps.

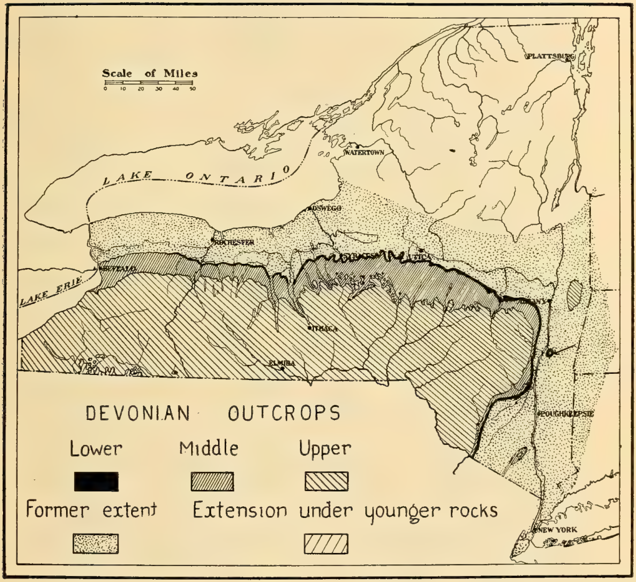


Figure 50 Devonian outcrops: Lower, Middle and Upper. The probable former extent of the seas of this period and the extension of the formations under those of younger age are shown.

New York formations. Devonian history in the area covered by the present state of New York is comparatively simple. Devonian rocks are more widespread here than rocks of any other age, covering nearly one-third the area of the State (figure 50), and they have a combined thickness of between 8000 and 9000 feet. The mass of sediments represented by the Catskill mountains is the most impressive single mass of Devonian rock in the country. The Devonian strata along the Hudson valley, as indicated by the outlier on the east side of the river, formerly extended some distance to the east into Massachusetts and perhaps the Connecticut valley. These beds standing out now as a bold escarpment facing the Mohawk valley must also have extended northward across this valley to the southern Adirondacks. The Silurian period passed into the Devonian with no disturbance. The great limestone deposits of the New York Devonian occur in the Lower and earlier Middle Devonian, the great bulk of the Devonian rock lying above the limestones and consisting of huge deposits of sandstones and shales. Except for the nonmarine deposits of the east, the Devonian rocks throughout abound in fossils of marine organisms. The Upper Devonian beds have furnished a wonderful flora of land plants including tree ferns (*Archaeopteris*), seed ferns (*Eospermatopteris*) and giant club mosses (*Protolepidodendron*). The discovery of the "Gilboa" tree (seed fern) in the Catskills has made that area famous and the "Naples" tree (club moss) has done the same for western New York.

The classification of the New York formations follows; dashes represent the absence of beds in the various sections.

DEVONIAN SYSTEM

Western	*West Central*	*Central*
UPPER	UPPER	UPPER
Chautauquan	**Chautauquan**	**Chautauquan**
Chemung beds	Chemung beds	Chemung beds
Chadakoin beds	—	—
Cuba s.s.		Fall creek cgl.
Northeast sh.		
Shumla s.s.		
Westfield sh.	Wellsburg s.s.	Wellsburg s.s.
Laona s.s.		
Gowanda sh.	Cayuta sh.	Cayuta sh.
Dunkirk sh.	Longbeards Riffs s.s.	
Senecan	**Senecan**	**Senecan**
Portage beds	Portage beds	Portage beds
(Naples fauna)	(Naples fauna)	(Naples-Ithaca fauna)
Wiscoy sh.	Wiscoy sh.	
Nunda s.s.	Nunda s.s.	Enfield sh.
	Prattsburg s.s. | High Point s.s.	
Gardeau sh.	Gardeau sh. | West Hill flags |	
—	Grimes s.s.	—
Hatch sh.	Hatch sh.	Ithaca sh.
Rhinestreet sh.	Rhinestreet sh.	—
Cashaqua sh.	Cashaqua sh.	Cashaqua sh.
		(Sherburne s.s.)
Middlesex sh.	Middlesex sh.	—
—	Standish sh.	—
West River sh.	West River sh.	—
Genundewa l.s.	Genundewa l.s.	—
Genesee black sh.	Genesee black sh.	Genesee black sh.
Tully l.s.	Tully l.s.	Tully l.s.
MIDDLE	MIDDLE	MIDDLE
Erian	**Erian**	**Erian**
Hamilton beds	Hamilton beds	Hamilton beds
Moscow sh. (*incl. Menteth l.s. at base*)	Moscow sh. (*incl. Menteth l.s. at base*)	Moscow sh. (*incl. Encrinal l.s. at base*)
Ludlowville sh. (*incl. Tichenor and Centerfield l.s.*)	Ludlowville sh. (*incl. Tichenor and Centerfield l.s.*)	Ludlowville sh. (*incl. Tichenor and Centerfield l.s.*)
Skaneateles sh. (*incl, supposed Cardiff sh. with Stafford l.s. at base*)	Skaneateles sh. (*incl. supposed Cardiff sh. with Stafford l.s. at base*)	Skaneateles sh. (*incl. Mottville l.s. at base*)
Marcellus sh.	Marcellus sh.	Marcellus sh. (*incl. Cherry Valley l.s.*)
Ulsterian	**Ulsterian**	**Ulsterian**
Onondaga l.s	Onondaga l.s	Onondaga l.s.
—	—	—
LOWER	LOWER	LOWER
Oriskanian	**Oriskanian**	**Oriskanian**
—	—	—
—	—	Oriskany s.s.
Helderbergian	**Helderbergian**	**Helderbergian**
—	—	—
—	—	—
—	—	—
—	—	—
—	—	Coeymans l.s.
—	—	
	(Upper Manlius: Keyser)	(Upper Manlius: Keyser)

DEVONIAN SYSTEM

East Central	*Eastern*	
UPPER **Chautauquan**	UPPER **Chautauquan**	
Chemung beds	Catskill beds	Rensselaer grit
Senecan	**Senecan**	
Portage beds	Portage beds	
(Ithaca fauna)	(Ithaca fauna)	
Oneonta s.s.	Oneonta s.s.	Skunnemunk cgl.
Ithaca sh.	Ithaca beds	
Sherburne s.s.	Sherburne s.s.	
——	——	
——	——	
——	——	
——	——	Bellvale sh.
——	——	
Tully horizon	——	
MIDDLE **Erian**	MIDDLE **Erian**	
Hamilton beds	Hamilton beds	
Hamilton sh.	Hamilton shales and flags	Cornwall sh.
Skaneateles sh.		
Marcellus sh. (*incl. Cherry Valley l.s.*)	Marcellus sh.	
Ulsterian	**Ulsterian**	
Onondaga l.s.	Onondaga l.s.	
Schoharie grit	Schoharie grit	
LOWER **Oriskanian**	LOWER **Oriskanian**	
Esopus grit	Esopus grit	
Oriskany s.s.	Oriskany s.s.	Glenerie l.s. Port Jervis l.s. Connelly cgl.
Helderbergian	**Helderbergian**	
——	Port Ewen l.s.	
Alsen l.s.	Alsen l.s.	
Becraft l.s.	Becraft l.s.	
New Scotland l.s.	New Scotland l.s.	
Kalkberg l.s.	Kalkberg l.s.	
Coeymans l.s.	Coeymans l.s.	
(Upper Manlius: Keyser)	(Upper Manlius: Keyser)	

The Devonian in New York State with some begins with the Coeymans; with others the Upper Manlius beds, considered of Keyser age (Lower Devonian of Maryland and West Virginia) are regarded as basal Devonian. This is discussed under the Manlius formation (p. 346). Four stages or epochs of the Devonian are recognized: the *Helderbergian,* named from the Helderberg plateau; the *Oriskanian,* which includes the Oriskany beds; the

Ulsterian, named from Ulster county; the *Erian* from the Lake Erie section and in its strict sense including the Hamilton beds and Marcellus shales (Clarke and Schuchert '99); the *Senecan,* from exposures in Seneca county and the *Chautauquan* from exposures in Chautauqua county.

The *Coeymans limestone* (Clarke and Schuchert '99) receives its name from the town of Coeymans, Albany county. In the older reports it was known as the "Lower Pentamerus" limestone from the most common brachiopod *Pentamerus galeatus* (now *Sieberella coeymanensis*). This limestone extends farthest west of any of the members of the Helderberg group, reaching the town of Manlius in Onondaga county where it is overlain by a thin representation of the Oriskany. The Coeymans limestone has a maximum thickness of 50 to 60 feet (in east central New York) and is the principal cause of the Helderberg cliff (figures 51, 52) into which also enters the underlying Manlius. It may be distinguished from the Manlius by the bluish gray color, which weathers light gray and the coarse granular texture. The beds are massive, more so in the lower part, and knotty, breaking up into irregular chunks. Shale partings occur occasionally, also nodules and thin lenses of chert. The Coeymans limestone is more silicious than the Manlius and the shells and crinoid stems which it carries tend to become silicified. The most common and characteristic fossil is the brachiopod *Sieberella coeymanensis* (*Pentamerus galeatus*), and next to this the brachiopods *Uncinulus mutabilis* and *Atrypa reticularis.* Other brachiopods reported from the Coeymans are *Stropheodonta* (*Brachyprion*) *varistriata, Camarotoechia semiplicata* and *Meristella laevis;* pelecypods as

Figure 51 Upper Silurian — Lower Devonian rocks. Complete section of Manlius and Coeymans limestones as seen in the Helderberg cliff, Haile's Cavern, Indian Ladder region, Albany county. (Photograph by E. J. Stein)

Actinopteria obliquata; trilobites as *Dalmanites micrurus* and *Proëtus protuberans;* the honeycomb coral, *Favosites helderbergiae* and large crinoid stems (*Melocrinus*) and the crinoid *Cordylocrinus plumosus.* The Coeymans limestone of Schoharie and Herkimer county has furnished a number of beautiful crinoids and strange cystoids. From the former area come the crinoids *Melocrinus nobilissimus, M. pachydactylus, Brachiocrinus nodosarius* and the cystoid *Lepocrinites* (*Lepadocrinus*) *gebhardi;* from the latter, the crinoids *Melocrinus paucidactylus* and *Lasiocrinus scoparius,* the cystoid *Anomalocystis cornutus* and the starfish *Hallaster forbesi.*

The Kalkberg limestone (Chadwick '08) is typically exposed along the Catskill creek, near Catskill, Greene county, and received its name from the local Dutch name for the Helderberg ridge (Kalkberg, meaning limestone mountain). The name was applied to certain beds betwen the Coeymans and typical New Scotland, variously included in these members previously, which have a wide distribution, carry a mixed fauna and are characterized by parallel seams of black flint. In the type section this limestone has a thickness of about 40 feet but the thickness varies in this area from 25 to 40 feet. In the Helderberg area only about 20 feet are represented. The Kalkberg is of a darker color, more impure, less granular and more fossiliferous than the Coeymans, and more silicious and less shaly than the New Scotland, though in certain areas, as the Helderbergs. there are thin, highly fossiliferous limestones interbedded with shales like those of the overlying New Scotland, and the beds weather a buff color. Where the chert beds are more heavy and the limestone more pure, as in the type area, the Kalkberg forms a cliff in con-

tinuation with or behind the Coeymans. In the Helderberg area it forms a low terrace below the New Scotland that is often quite conspicuous in the topography. The upper beds are more impure and grade into the shaly limestone above. Fossils here are even more abundant, especially the smaller ones and bryozoans which are very characteristic. Bryozoans are represented by many genera (*Hallopora, Fistulipora, Monotrypa* etc.). Brachiopods form a large part of the fauna. The lower beds are marked by the characteristic *Bilobites varicus;* among other forms listed are *Spirifer macropleura* and *S. cyclopterus, Spirifer* (*Delthyris*) *perlamellosus, Sieberella coeymanensis, Atrypa reticularis, Anastrophia verneuili, Leptaena rhomboidalis, Dalmanella perelegans, Rhipidomella oblata, Eatonia medialis, Uncinulus abruptus, Strophonella leavenworthana, Nucleospira ventricosa, Meristella laevis* etc. The trilobite genera *Phacops* (*P. logani*) and *Dalmanites* (*Odontochile*) are represented. Large crinoid stems (*Mariacrinus stoloniferus*) are characteristic. Corals are represented by the honey comb coral *Favosites helderbergiae* and the cup coral *Streptelasma* (*Enterolasma*) *strictum;* and the sponge *Hindia inornata* occurs.

The *New Scotland limestone* (Clarke and Schuchert '99) known in older reports as the "Catskill shaly," "Delthyris shaly" or "Lower shaly" limestone received its name from the town of New Scotland, Albany county. It continues westward without interruption into Herkimer county where it disappears, due to uplift and erosion, and here the Onondaga rests upon the Coeymans. Farther west, in Madison county, there is evidence that it reappears, but except for this the Oriskany is the only intervening formation and west of the central part of

the State is the basal Devonian formation. The New Scotland limestone, with a thickness of approximately 75 to 100 feet, is the least conspicuous and most fossiliferous member of the Helderbergian series. It consists of thin-bedded, very impure, shaly limestones and calcareous shales which tend to be heavier and less fossiliferous, at least in certain areas as the Indian Ladder in the Helderbergs where in the lowest 20 feet or so only the brachiopods *Lingula* and *Orbiculoidea* were found and these sparingly. Locally seams of black chert appear in the uppermost 20 feet or so. The middle beds are, on the whole, the most fossiliferous. In fresh exposures the rock has a dark bluish gray color and massive appearance and looks like a true limestone. When weathered these beds have a gray or gray-brown color. In general fossils occur in the New Scotland only as impressions or natural molds but in certain areas where the limestone is more silicious, the fossils have become silicified. The New Scotland beds, were known in the old days as the "Delthyris shaly limestone" because of the common and characteristic brachiopods *Spirifer* (*Delthyris*) *perlamellosus* and *S.* (*Delthyris*) *macropleura* Brachiopods form a large and conspicuous part of the New Scotland fauna and bryozoans are numerous. Next in abundance to the brachiopods are the gastropods. Besides the common *Spirifers,* among the brachiopods are found *Leptaena rhomboidalis, Stropheodonta* (*Leptostrophia*) *becki, Strophonella headleyi, Eatonia medialis, Orthostrophia strophomenoides, Meristella laevis* and *M. arcuata, Dalmanella perelegans* and *D. subcarinata, Rhipidomella oblata* and *Camarotoechia acutiplicata.* The pelecypods are represented by *Actinopteria communis* and *A. textilis, Aviculopecten tenuilamellatus* and *Pterinea halli;* the gastropods by *Diaphorostoma ventri-*

cosum and several species of *Platyceras* (*P. ventricosum, P. gebhardi, P. retrorsum, P. spirale* etc.) ; the trilobites by *Dalmanites* (*Odontochile*) *pleuroptyx, Dalmanites nasutus, Lichas pustulosus, Phacops logani and Ceratocephala tuberculata.* Among other fossils found are the cup coral *Streptelasma* (*Enterolasma*) *strictum,* the sponge *Hindia inornata,* the pteropod *Tentaculites elongatus* and the cephalopod *Orthoceras rude.* Crinoids are represented by the base *Aspidocrinus callosus* and *Edriocrinus pocilliformis.*

The *Becraft limestone* (Darton '94) received its name from the exposure in Becraft mountain, Columbia county. Previously it was known as the "Scutella" or "Encrinal" limestone, from the presence of numerous crinoid bases or Scutellas, and also as the "Upper Pentamerus" limestone because of the occurrence of the brachiopod *Sieberella* (*Pentamerus*) *pseudogaleata.* The rock is very coarse-grained and not infrequently has the character of a shell rock or coquina. Though usually somewhat darkened on weathering, the rock is light colored with pinkish and light gray, sometimes yellowish tints. It is a very pure limestone on the whole and massive, forming conspicuous ledges. Chert is unusual. The lower part of the formation is thinner-bedded with seams of silicious shale, sometimes of a greenish color, one to several inches thick. These seams have an abundance of silicified fossils among which *Atrypa reticularis* is common. The transition from the New Scotland to the Becraft is not sharp, since the lower Becraft has partings of shale and in the upper New Scotland occur limestone bands that are packed with crinoidal fragments. The Becraft limestone thickens southward and in the type section at Becraft mountain near Hudson, where it

is extensively quarried for Portland cement, has a thickness of 45 feet. At Rondout there are 35 feet of this limestone. In the Helderberg area the beds vary from nine to 27 feet, only the lowest beds (nine feet) with shale seams appearing in the Indian Ladder area. At Schoharie there are about 15 feet of Becraft. There are some very characteristic fossils as the shieldlike crinoid base or anchor *Aspidocrinus scutelliformis,* which is found throughout the Becraft, sometimes in great abundance, and also occurs in the upper New Scotland. The brachiopod *Sieberella (Pentamerus) pseudogaleata* is also abundant and characteristic. Among other brachiopods commonly found are *Atrypa reticularis, Spirifer concinnus, Uncinulus nobilis* and *Schizophoria multistriata;* less commonly *Leptaena rhomboidalis, Uncinulus campbellanus, Rhipidomella oblata, Wilsonia ventricosa, Meristella princeps.* A number of gastropods occur but they are not at all abundant. One of the commoner forms is *Trematonotus profundus.*

The *Alsen limestone* (Grabau '19) is the name proposed for cherty limestones which overlie the Becraft and bear the same relation to it as the Kalkberg does to the Coeymans. It was originally included in the Port Ewen as a basal phase. The formation was named from the section at Alsen, N. Y. (where the Port Ewen is absent) and is well shown in the hills about Alsen, in Becraft mountain and at Schoharie. At Becraft mountain and Schoharie it is followed by the Oriskany sandstone, at Kingston and Port Ewen by the Port Ewen beds. The Alsen, like the Kalkberg, is a more impure limestone than the beds below. Basal Alsen is light colored but finer-grained than the Becraft, but it quickly becomes a dark blue-gray in color, often weathering into buff

colors. This limestone has a thickness of 20 to 50 feet or so; at Port Ewen the thickness is about 30 feet, in the Catskill area about 20 feet, 25 feet at Becraft mountain, 10 to 15 feet at Schoharie. The fossils are more silicified than in the Becraft below. In the field two fossils will always distinguish it from the Kalkberg, the brachiopod *Spirifer concinnus* and the bryozoan *Monotrypa tabulata.* The fauna is a modified Becraft fauna.

The *Port Ewen beds* (Clarke '03) are a series of shaly limestones lying above the Alsen limestone and similar in character and fossil content to the shaly limestones (New Scotland) underlying the Becraft. When first shown to be a unit they were described as the "Upper Shaly beds" (Davis '83). Later (Clarke and Schuchert '99) changed the name to Kingston beds, but as the name was preoccupied they were later called Port Ewen beds from the town of that name, opposite Rondout, where they are best exposed. They have their best development in southeastern New York where the maximum thickness is about 200 feet. These beds are missing in the Helderberg sections northwest of the Catskill area and at Schoharie beds formerly considered Port Ewen are now considered Alsen limestone. At Rondout the Port Ewen has a thickness of about 150 feet, 30 to 35 feet in the Saugerties region and five or six feet in Austin's Glen, Catskill. These limestones are darker and more argillaceous than the Alsen, the dark color of the fresh rock usually turning gray in weathering; they are also less fossiliferous than either the Alsen or the New Scotland. A list of some of the fossils will show the similarity of the fauna to that of the New Scotland. The brachiopods *Spirifer concinnus, S. cyclopterus,* rarely *S. macropleura, S.* (*Delthyris*) *perlamellosus,*

Leptaena rhomboidalis, Stropheodonta (Leptostrophia) becki, Rhipidomella oblata, Meristella laevis and M. princeps, Anastrophia verneuili, Eatonia medialis and *E. peculiaris, Dalmanella planoconvexa, Schuchertella woolworthana* familiar to us from the lower beds, occur here; also the trilobites *Phacops logani, Dalmanites (Odontochile) pleuroptyx,* the pteropod *Tentaculites elongatus,* the coral *Pleurodictyum lenticulare,* the sponge *Hindia inornata.* The fauna is predominantly New Scotland, though the transitional character of the Port Ewen to the Oriskany is indicated by the presence of a few Oriskany species such as *Meristella lata* and *Spirifer murchisoni.* The presence of the latter has led to the placing of the Port Ewen with the Oriskany but these beds seem more properly to belong in the Helderbergian where they were placed at first.

The *Oriskany sandstone* receives its name from the type locality at Oriskany Falls, Oneida county, where it consists of a nearly pure, white fossiliferous quartz sand rock, 20 feet in thickness. This sandstone represents shore deposits of the transgressing sea in Oriskany time. The early Oriskany sea was restricted to the eastern part of the present Helderberg area. When the westward transgression of this sea occurred the subsiding land surface was more or less irregular due to elevation and erosion at the end of Helderbergian time. In the east the lower Oriskany beds rest upon the Port Ewen, the upper member of the Helderbergian. In the northern Helderbergs the Oriskany rests upon Becraft, in the Schoharie area on the Alsen, at Litchfield in Herkimer county on the Coeymans, in central New York on the Manlius and in western New York and Canada on the Cobleskill. From Manlius (Onondaga county) on westward the so-called

Oriskany sandstone occurs as a series of thin lentils, sometimes not appearing at all or represented only by scattered sand grains or sand fillings in crevices in the rock below. This is considered the clastic initial deposit ot the Onondaga (Ulrich). In the east the Oriskany formation is represented by both arenaceous and calcareous sediments. In the Cobleskill-Schoharie area the rock is a mixture of quartz and lime grains. When the rock is exposed the lime is commonly dissolved out leaving a brown, porous sand-rock in which the fossils are beautifully preserved as both internal and external molds. The formation in this area has a maximum thickness of five or six feet, in some places being only one or two feet or less thick, perhaps missing in others. In the northern Helderberg area the rock is similar, with a maximum thickness of about four feet. Because of the flinty nature of the rock it is very resistant and wherever the beds are more or less horizontal forms a level platform or terrace, the softer Esopus beds above having been eroded, with the surface covered with the characteristic worm burrows *Taonurus cauda-galli* or "Cocktails" which also mark the Esopus shales. Going southward from here the rock soon changes in character and becomes a chert or cherty limestone. In the Catskill area in Greene county it no longer has its typical appearance, though characterized, as the typical beds, by the brachiopod *Spirifer arenosus,* and still is only a few feet in thickness. Farther southward it thickens more and more and highly fossiliferous limestone beds come in at the top and still farther south a basal pebble conglomerate (18 to 20 feet thick) also of Oriskany age. To that fossiliferous limestone in Ulster county Chadwick ('08) has given the name *Glenerie limestone* from its occurrence

at the old lead mills on the Esopus that bore the name Glenerie. The basal conglomerate he termed the *Connelly conglomerate* from its typical exposure on the hill above South Rondout (Connelly post-office). In Orange county the beds representing Oriskany were divided (Shimer '05) into Lower Oriskany (30 feet), the *Dalmanites dentatus* zone with Helderbergian and Oriskany species; and the Upper Oriskany (150 feet), the zone of *Spirifer murchinsoni.* The *Dalmanites dentatus* zone has been called the *Port Jervis limestone* (Chadwick '08). The Glenerie limestone is dark blue in color, silicious, and weathers to gray and finally buff colors. Chert bands occur more or less frequently and in places it becomes very shaly. The characteristic Oriskany fossils are the brachiopods, among which are conspicuous forms as *Spirifer arenosus* and *Spirifer murchinsoni, Rensselaeria ovoides, Hipparionyx proximus, Megalanteris ovalis, Leptostrophia magnifica, Plethorhyncha barrandei,* and *P. pleiophleura, Camarotoechia oblata, C. pleiopleura, Rhipidomella musculosa* and smaller forms as *Meristella lata, Eatonia peculiaris* and *Leptocoelia flabellites.* Gastropods are represented by *Diaphorostoma ventricosum, Platyceras nodosum, Cyrtolites expansus, Strophystylus expansus;* pelecypods by *Pterinea textilis* var. *arenaria, Pterinea gebhardi.*

The deposits of Oriskany age in southeastern New York (Port Jervis region) are considered as representing a deep-water or calcareous phase of the shallow-water, typical Oriskany sandstone. As mentioned above, the lower beds (Port Jervis) or *Dalmanites dentatus zone,* have a mingled Helderbergian and Oriskanian fauna, and they carry besides the especially abundant *D. dentatus,* the trilobite *Homalonotus vanuxemi.* The

Glenerie limestone has in its fauna the characteristic large brachiopods and other forms of the Oriskany sandstone and with these a number of smaller forms. The pteropod *Tentaculites elongatus* occurs, the trilobites *Dalmanites* (*Synphoria*) *stemmatus, Homalonotus vanuxemi* and *Phacops logani,* and the crinoids *Edriocrinus sacculus* and *Ancyrocrinus quinquepartitus.* These beds also show the characteristic *Taonurus cauda-galli.* The most characteristic fossil of the Upper Oriskany limestone of Orange county is *Spirifer murchisoni,* hence the name *Spirifer murchisoni zone.* Certain of the large, typical Oriskany fossils (as *Rensselaeria ovoides, Hipparionyx proximus*) are absent from the Port Jervis region, which might be accounted for by depth of water (Shimer '05) and there is also a persistence of Helderbergian species in this region to the beginning of the Esopus.

The *Esopus shales* or *Esopus grit* (Darton '94) was named after the excellent exposures near the Esopus settlement (Kingston) and along the creek of that name. This is the *"Cauda-galli grit"* of Vanuxem ('42) socalled from the abundant markings on the bedding planes which resemble a rooster's tail. These shales are not found west of Otsego county, but the formation is a persistent one in eastern New York, New Jersey and Pennsylvania. The Esopus grit is a blackish or dark gray grit or sandy shale of a very uniform character which readily crumbles to gravel and weathers to a dark brown color. The aspect of this rock varies according to the way in which the cuts are made. In certain cuts the surface is covered with small, cubical blocks, resembling a pile of stone, but other cuts are made in such a way that the rock appears very solid

and resistant. In the northern Helderberg area the lower eight or ten feet of the grit in places was found to be highly silicious or flinty and filled with the Taonurus-markings, indicating a close relation with the Oriskany sandstone of which it is considered a facies. The middle beds are more argillaceous and the uppermost beds again more strongly silicious, passing gradually into the Schoharie grit above. The more cherty character of the grit has been found in a greater thickness in the lower beds in the Catskill area (Chadwick) and in the Esopus creek these beds are very flinty. Where involved in folding the Esopus shales have their greatest thickness in southeastern New York. At Becraft mountain and at Rondout there are about 300 feet, including the Schoharie, and at Port Jervis about 700 feet. In the northern Helderberg area there is a thickness of 100 to 120 feet and in the Schoharie area 80 to 90 feet. As stated above the beds are practically barren. Fossils have been reported from the Esopus creek area and a few fossils, mostly brachiopods, have been found in lower silicious beds of the Catskill area (Chadwick).

The *Schoharie grit* (Vanuxem '40) receives its name from the type locality in Schoharie county (at Schoharie). It is a formation of somewhat local development, occurring also in Albany and Otsego counties and in the Hudson valley but apparently not everywhere continuous. It is characterized by a great wealth of fossils, quite in contrast to the Esopus shales. The formation is characteristically developed in the Schoharie valley where it is an impure silicious limestone, dark bluish gray in color when fresh and weathering to a dark buff or brown porous sandstone. Some parts of the rock are shaly and rather sparingly fossiliferous. In the Schoharie area

the Schoharie grit has a thickness of five or six feet; in the northern Helderberg and Capital District area it varies from nothing to a thickness of about eight feet. Farther east, or southeast, it thickens. A thickness of about 100 feet has been found in the Catskill area and there it is more of a fine-grained impure limestone (Chadwick). At Becraft mountain 150 to 200 feet of shale are referred to the Schoharie, because some of the characteristic fossils have been found in it, though in rock aspect the shale is more similar to the Esopus. The variable occurrence of the Schoharie grit and its character in the northern Helderberg and Capital District area suggest that it is a sandy facies of the Onondaga. Not only is it found merging into the overlying Onondaga, with the lower Onondaga somewhat sandy, but interfingering of the grit and the limestone has been observed and fossils (corals and cephalopods) have been found passing freely across the welded contacts. On the other hand disconformities at the top and bottom of the Schoharie grit, indicated by the presence of glauconite have been reported from the Catskill region (Chadwick). Thin as the formation is, the wealth of fossils in the Schoharie grit is astonishing. In this fauna occur species of the corals *Zaphrentis* and *Streptelasma,* the brachiopods *Atrypa impressa, Pentamerella arata, Meristella nasuta, Strophonella ampla, Stropheodonta demissa, Leptostrophia perplana, Rhipidomella alsa, Delthyris raricostata, Chonetes hemisphericus;* the pelecypods *Panenka dichotoma, Conocardium cuneus, Goniophora perangulata;* the gastropods *Bellerophon pelops* and *Pleurotomaria arata;* the cephalopods, *Orthoceras thoas, O. pelops, O. zeus,* etc., *Cyrtoceras eugenium, Trochoceras eugenium* and *T. clio;* the trilobites *Dalmanites anchiops*

var. *armatus, Phacops cristata, Proëtus crassimarginatus Calymene platys,* etc.

The *Onondaga limestone* (Hall '39) has a very wide distribution and extends with very uniform character of the rock and fauna from New Jersey in the southeast, across the State into Ontario, Canada. The name was derived from its occurrence in Onondaga county. The present name now includes all divisions of the formation to which the names Onondaga (Hall), Corniferous (Eaton) and Seneca (Vanuxem) limestone were applied in western New York. The "Corniferous" was the cherty division and the purer upper limestone was the "Seneca." The Onondaga is a moderately pure limestone of light bluish color, often thinly bedded in the lower portion but in general massive. Lenses of chert in parallel layers occur, particularly in the lower part of the formation, but its distribution is very irregular and it has been found to be abundant in some places, sparse in others. The uppermost beds ("Seneca") are free from chert, and often the very lowest beds. The maximum thickness of the Onondaga in the western part of the State is between 150 and 200 feet. The thickness is about 100 feet in the Schoharie area, 85 to 100 feet in the northern Helderberg area and southward from this it thins somewhat until in southeastern New York (Kingston area) it has a thickness of 50 feet or more. At Becraft mountain (Hudson) there is only a thickness of 25 feet, but the Schoharie sandy phase is about 200 feet thick here. In the Catskill area the thickness is not a great deal less than in the Helderbergs. The Onondaga limestone fauna is characterized by corals, an abundance of individuals rather than species. Much of the limestone was probably formed by coral reefs. Among

the corals are *Favosites basalticus, F. emmonsi, F. epidermatus, F. hemisphericus, Zaphrentis prolifica, Z. gigantea, Z. corniculum, Cyathophyllum robustum, Phillipsastraea* sp., *Acervularia* sp. etc.; brachiopods are represented by such large forms as *Amphigenia elongata,* the index fossil of the Onondaga, *Spirifer divaricatus, Strophonella ampla, Stropheodonta hemispherica* and other forms as *Spirifer duodenarius, Spirifer acuminatus, Meristella nasuta, Pentagonia unisulcata, Athyris spiriferoides, Atrypa reticularis, A. spinosa, Pentamerella arata, Delthyris raricostata;* pelecypods by *Aviculopecten parilis, Lyriopecten dardanus, Megambonia cardiformis, Plethomytilus ponderosa;* gastropods by *Platyceras dumosum, P. undatum, P. symmetricum, Diaphorostoma lineatum, Pleurotomaria decewi, P. arata, Phanerotinus laxus, Euomphalus decewi;* cephalopods by *Gyroceras (Ryticeras) trivolve, G. undulatum, G. matheri, G. (Halloceras) paucinodum, Poterioceras eximium, Dawsonoceras thoas;* pteropods by *Tentaculites scalariformis;* trilobites by *Dalmanites (Odontocephalus) selenurus, Dalmanites (Odontochile) calypso, Lichas (Conolichas) eriops, Proëtus crassimarginatus.* A number of species of crinoids are found in the limestone, *Arachnocrinus bulbosus, Craterocrinus ruedemanni, Dolatocrinus speciosus* etc. and fish remains occur.

The *Kanouse sandstone* (Kümmel '08), occurring in the Devonian outlier in southeastern New York (Orange county) and New Jersey and named from the mountain in northern New Jersey, is considered of Ulsterian age (from Ulster county) and carries Onondaga fossils. The formation has a thickness of 215 feet.

The *Hamilton beds* were named originally from typical exposures at West Hamilton, Madison county (Vanuxem

Figure 52 Upper Ordovician — Middle Devonian rocks. Indian Ladder beds (lower right) of Ordovician age; the Brayman shale, Rondout waterlime and Manlius limestone of Silurian age (in cliff) and the Devonian rocks from the Coeymans limestone (in cliff) to the Hamilton beds (hills in background). Indian Ladder region, the Helderbergs, Albany county. (Photograph by E. J. Stein)

'40). These beds which are represented in the east by sands and arenaceous shales and in the west by black shales, calcareous shales and limestones, are on the whole richly fossiliferous. The Hamilton beds form a thick wedge of clastic materials which thin westward with numerous accompanying shifts or facies both in the character of the rock and the fauna. Hall and Vanuxem in their final reports included in this group the Skaneateles shale, Olive shale, Ludlowville shale, Encrinal limestone and the Moscow shale. Dana enlarged the term to include the Marcellus shales and the Tully limestone. Until recently the term has been used to include everything between the Cardiff shales and the Tully limestone, that is, the Skaneateles, Ludlowville and Moscow formations. Very recent studies of the Hamilton beds have shown the necessity for some revision, and for the details the student is referred to the paper embodying the results (Cooper '30). These studies have shown "that the black muds of the Marcellus, often affiliated with the Onondaga, thicken eastward and are gradually replaced by gray arenaceous shale. Concordantly the Marcellus fauna grades eastward into one of Hamilton aspect. These phenomena have made it necessary to place the Marcellus formation in the Hamilton group, which, therefore, now consists in ascending order of the Marcellus, Skaneateles, Ludlowville and Moscow formations. The Skeaneateles formation and several members in the higher formations show a similar westward shift of faunal facies from one of Hamilton aspect in the east to a modified Marcellus fauna in the west" (Cooper '29; Geol. Soc. meeting abstract). It has also been found that the Mottville limestone, regarded as the base of the Skaneateles formation at its type section, is the equivalent

of the Stafford limestone in the western part of the State, thus making the Cardiff shales,[1] hitherto considered the upper member of the Marcellus formation, a modified Marcellus facies of the Skaneateles formation. Similarly the "Encrinal limestone" of the Cayuga lake section, which is the accepted base for the Moscow shales, corresponds not to the Tichenor limestone, the accepted base of the Moscow shales in western New York, but to the Menteth limestone lentil which is 50 feet above the Tichenor limestone in the Canandaigua lake section. The Tichenor limestone eastward becomes shaly, disappearing in the vicinity of Seneca lake. These facts make a redefinition of the Moscow necessary. The Centerfield limestone lies at the base of the Ludlowville shale. Upon tracing it eastward into the type section of the group at the village of Hamilton, Madison county, it was found that the beds there are of Skaneateles age instead of Ludlowville. The highest Hamilton shales in Schoharie county have been found to carry what is believed to be the Skaneateles fauna, and it is suggested that at least part of the Sherburne sandstone in the Schoharie valley is of Hamilton age and represents the Moscow and at least a portion of the Ludlowville. The westward disappearance of successive faunal zones at the top of the Hamilton indicates unconformable relations between the Hamilton and the Upper Devonian (Cooper '30). Our Hamilton shales in the east (figure 52) have not yet been divided; in the southeast, in Ulster county, the lower fossiliferous beds (marine) have been called the Mount Marion beds, the upper, nonfossiliferous (nonmarine) beds, the Ashokan formation. It has been suggested (Cooper '30) that the nonmarine Ashokan beds may represent all of the upper Hamilton and the

[1] See footnotes on pages 390 and 391.

marine Mount Marion beds the Cardiff shales; or that the former are the time equivalent of the Moscow and Ludlowville and the latter, of the Cardiff and Skaneateles. The Hamilton beds, including the Marcellus, have an aggregate thickness of about 1500 to 1600 feet in New York state.

The *Marcellus beds* (Hall '39) were named from exposures at Marcellus, Onondaga county and now include the black shales and the *Cherry Valley limestone* (Clarke '03).[1] The Marcellus black shales follow the Onondaga quite abruptly and an unconformity is indicated in eastern New York (Chadwick '27). There are about 200 feet more or less of these shales. Typically the Marcellus is a black bituminous, pyritiferous, very fissile shale, which is also characterized by numerous concretions of carbonate of lime scattered through certain portions of it. These concretions vary in size from a few inches to several feet in diameter and appear to be most abundant near the middle of the bed. The Marcellus occurs in the Hudson valley and extends across the State, thinning westward. Near the base of the black shale are included calcareous layers characterized by goniatites (cephalopods), the *Cherry Valley* (*Agoniatite*) *limestone* (Clarke '03) which extends from the Schoharie area to Ontario county as distinct layers. The fauna of the Marcellus black shales is meager and in the east distinctly Hamilton in character. The characteristic brachiopod *Liorhynchus limitaris* is generally found, also the pelecypod *Lunulicardium marcellense*. The pteropod *Styliolina fissurella* occurs in thin bands in countless numbers. Other species are the brachiopods *Chonetes mucronatus, Leiorhynchus mysia, Strophalosia truncata,*

[1] Cardiff shale of type locality, which lies below the Mottville and disappears westward before Cayuga lake, belongs with Marcellus formation (see page 391).

Oehlertella exilis and Orbiculoidea minuta; the pelecypods *Panenka equilatera, Aviculopecten equilaterus; Leiopteria laevis* and *Nuculites triqueter;* the gastropods *Euryzone* (*Pleurotomaria*) *rugulata,* and (in the Cherry Valley limestone) *Euomphalus planodiscus* and *Loxonema hamiltoniae.* The cephalopods are most characteristic of the Agoniatite (Cherry Valley) limestone, among them *Orthoceras marcellense, Gomphoceras* (*Poterioceras*) *oviforme, Nautilus* (*Discites*) *marcellensis, Agoniatites expansus, Anarcestes plebeiformis,* and *Parodiceras discoideum.*

The *Skaneateles formation* (Vanuxem '40) now includes the Stafford limestone, Cardiff shale[1] and Skaneateles shale. The *Stafford limestone* (Bishop '97) has recently been proved to be the equivalent of the *Mottville limestone* (Smith '16) of central New York which is considered the basal member of the Skaneateles shale. The Stafford has a thickness of about three feet in western New York and extends from Erie county to Flint creek in Ontario county and is recognized by its fossils as far east as Cayuga county. The name was given from exposures at Stafford, Genesee county. Though the limestone is not thick it carries a very abundant fauna of brachiopods (*Chonetes scitulus, Stropheodonta inequistriata, Strophalosia truncata, Camarotoechia sappho, Meristella barrisi, Rhipidomella vanuxemi, Spirifer audaculus*), pelecypods (*Leiopteria laevis, Leptodesma marcellense, Panenka equilatera*), gastropods (*Euryzone* [*Pleurotoma*] *itys, E. lucina, Bembexia sulcomarginata, Diaphorostoma lineatum, Bellerophon lyra, Loxonema hamiltoniae*), cephalopods (*Geisonoceras subulatum, Spyroceras nuntium, Kionoceras staffordense, Tornoceras uniangulare*), and trilobites (*Phacops rana*

[1] Only the supposed Cardiff shale of western New York above the Stafford limestone belongs here (see page 390).

and *Cryphaeus boothi* var. *calliteles*). The *Cardiff shale* (Clarke and Luther '04) was named from Cardiff, Ontario county. It represented the upper Marcellus of Vanuxem, recognized as a division from Schoharie westward, overlying the Marcellus black shale or Stafford limestone, where present. It is now regarded as a modified Marcellus facies of the Skaneateles shale. In the type locality it is dark calcareous and black slaty shale with thin layers of fossiliferous limestone. Its grayer aspect and higher calcareous content distinguish it from the black shales below. Thicknesses varying from 50 to 175 feet are recorded. These shales farther east in central New York are not very fossiliferous. They grade above into the *Skaneateles shale* (Vanuxem '40), named from Skaneateles lake in Onondaga county and recognized from east central New York to the western limits of the State. At the base the shale is hard, dark bluish or black and calcareous, passing into somewhat lighter and softer beds above, and containing several rows of small concretions. In the extreme western part of the State along Lake Erie it has a thickness of 40 or 50 feet. The thickness increases eastward being recorded as 125 feet in Ontario county and 385 feet in the Onondaga valley in Onondaga county. Fossils occur more abundantly in the lower calcareous shales.

The *Ludlowville shale* (Hall '39) and *Moscow shale* (Hall '39) constitute the upper part of the Hamilton beds and both are very rich in fossils of the typical Hamilton fauna. The *Ludlowville shale* received its name from Ludlowville, Cayuga county, and is recognized from east central New York to the western limits of the State. The shale is mostly fine and soft, evenly bedded, light to dark bluish gray in color and but slightly calcareous. In the lower part there are several thin layers of lime-

stone and calcareous concretions are common. These lower calcareous beds have been called the *Centerfield limestone* (Clarke '03). This horizon extends as far west as Erie county and also has been traced eastward to the type locality of the Hamilton in Madison county. The Ludlowville shale has a thickness of about 60 feet in the Buffalo area. The thickness increases eastward to 125 feet in Ontario county and 350 feet or more in Onondaga county. The *Moscow shale* formation consists of soft, light bluish gray shales that are usually somewhat calcareous and in some exposures show continuous concretionary layers crowded with fossils. This shale has a thickness of 15 to 50 feet in the western part of the State and thickens eastward to about 200 feet in the central part. In western New York there lies between the Ludlowville and Moscow shales, as previously defined, a limestone band 1½ to 2 feet thick that persists eastward for more than a hundred miles. To this stratum has been given the name *Tichenor limestone* (Clarke '03) from the exposure at Tichenor point on the west shore of Canandaigua lake, Ontario county. It carries an abundant Hamilton fauna. Fifty to 75 feet above the Tichenor limestone is another limestone layer lying in the midst of the shale mass and designated the *Menteth limestone* (Clarke and Luther '04) from Menteth point, Canadaigua lake. The bed is noteworthy for the fine replacement of the fossils by silica. The "Encrinal limestone" of Cayuga lake, as pointed out above, has now been found to correlate farther west with the Menteth instead of the Tichenor limestone, which eastward becomes shaly and disappears in the vicinity of Seneca lake. This places the Tichenor limestone within the Ludlowville and makes the Menteth limestone the base of the

Moscow. In Erie county the Menteth limestone, through overlap, comes to rest upon the Tichenor limestone but thins out and disappears before reaching the lake shore (Cooper '30).

The Hamilton fauna is very rich, containing over 800 species of which 300 are common throughout the State (Ibid). The fauna is particularly notable for its pelecypods which flourished on the muddy bottoms of the Hamilton sea and attained an unequalled profusion of individuals and development of forms. Corals are abundant and there is an abundant crinoid fauna, more characteristic of the calcareous layers, however. In this fauna corals are represented by *Heliophyllum halli, Zaphrentis simplex, Streptelasma rectum, Pleurodictyum (Michelinia) styloporum, Favosites hamiltoniae, Cyathophyllum galerum, Cystiphyllum varians, Acervularia davidsoni, Alveolites goldfussi* etc.; crinoids by *Dolatocrinus liratus, Clarkeocrinus troosti, Gennaeocrinus eucharis, Rhodocrinus nodulosus, Thylacocrinus clarkei, Megistocrinus depressus, Taxocrinus lobatus, Botryocrinus nycteus* etc.; brachiopods by *Chonetes scitulus, C. coronatus, Ambocoelia praeumbona, Cyrtina hamiltonensis, Camarotoechia prolifica, Nucleospira concinna, Tropidoleptus carinatus, Rhipidomella vanuxemi, R. penelope, Delthyris consobrina, Stropheodonta perplana, S. demissa, Atrypa reticularis, A. spinosa, Athyris spiriferoides, Spirifer granulosus, S. mucronatus, S. audaculus* etc.; pelecypods by *Actinopteria boydi, Pterinopecten undosus, Lyriopecten tricostatus, Leiopteria dekayi, Pterinea flabellum, Aviculopecten princeps, Limopteria curvata, Buchiola halli, Lunulicardium curtum, Cimitaria elongata, Grammysia bisulcata, Sphenotus solenoides, Panenka radians, Paleoneila emarginata, Nucula bellistriata, Goniophora*

hamiltonensis, Cypricardella bellistriata, Modiomorpha mytiloides, Glyptodesma erectum; gastropods by *Diaphorostoma lineatum, Loxonema hamiltoniae, Phanerotinus laxus, Platyceras bucculentum, Bellerophon leda, B. rudis, Bembexia sulcomarginata, Euryzone rugulata, E. lucina;* cephalopods by *Orthoceras exile, Geisonoceras subulatum, Spyroceras crotalum, Tornoceras uniangulare, Parodiceras discoideum;* trilobites by *Proëtus rowi, Phacops rana, Homalonotus (Dipleura) dekayi, Dalmanites (Cryphaeus) boothi.* Other crustaceans found are *Leperditia punctulifera* and *Echinocaris punctata;* and conularids such as *Hyolithes actis* and *Conularia undulata* occur. The worm burrow *Taonurus velum* is quite characteristic.

In the eastern part of the State the Hamilton beds above the Marcellus black shales have always been discussed as a unit, the Hamilton shales and flags. In Ulster and Greene counties, the Hamilton has been divided into two formations. The lower formation includes the fossiliferous marine beds, 400 to 500 feet thick and designated as the *Mount Marion beds* (Grabau '19) from Mount Marion west of Saugerties; the upper formation contains nonmarine, nonfossiliferous, flagstone-bearing beds, with a thickness of 500 to 600 feet, and has been termed the *Ashokan shales and flags* (Grabau '19). The *Cornwall shale* (Hartnagel '07; for Darton's "Monroe shale") was named from exposures found at the town of Cornwall, Orange county. These shales, 200 feet thick, extend through the town of Monroe into New Jersey and carry fossils indicative of Hamilton age. The *Bellvale shales* (Darton '94) also occur in Orange county and New Jersey, overlying the Cornwall shale. These beds have a thickness of 1300 to 2000 feet, and

the plant remains found indicate Middle Devonian age. They were named from Bellvale mountain in Orange county.

The Upper Devonian in New York State has the *Tully limestone* (Vanuxem '39) as a basal formation. It receives its name from the fine exposure at the town of Tully in Onondaga county. As a formation this limestone does not occur west of Canandaigua lake, but the horizon beyond this to the western limits of the State is marked by a thin layer of iron pyrites (one to four inches) containing a dwarf fauna. In the other direction the formation does not extend east of the Chenango river but the horizon with the characteristic fossils is found as far east as Otsego county. The Tully limestone itself carries considerable quantities of pyrites and has a thickness of ten to about 30 feet. The fauna of this limestone is essentially only a modification of the Hamilton species. *Hypothyris cuboides* (*Hypothyridina venustula*) the index species of early Upper Devonic time, worldwide in distribution, is present. There is also the very characteristic trilobite *Scutella* (*Bronteus*) *tullius*. The fauna of the pyrite layer is a dwarf fauna, showing arrested development due to the unfavorable conditions under which the animals lived. However, the fauna, though so diminutive, is a rich one consisting of crustaceans, cephalopods, pelecypods, gastropods, brachiopods and crinoids. Corals are entirely wanting.

The *Genesee beds* (Vanuxem '42) were first known as the "Upper black shale" in distinction to the Marcellus black shale. Then the name "Genesee shale" came into use, but only for the shales between the Tully limestone and the Genundewa limestone. Later the shales above and below the limestone came to be included under the

term and the name Genesee (in the restricted sense) was applied to the lower shales, the Genesee black shale, the upper shales receiving the name of West River shale. The name Genesee is used here, as originally, for the black shale only. All of the Senecan above belongs to the Portage (Ulrich). The *Genesee black shale* comprises the shales between the Tully and Genundewa limestone which extend as far east as the Chenango valley (central New York). They are densely black, bituminous layers with thin bands of gray shales appearing near the top. Pyrites in small nodules is common, and there sometimes occur a few thin flags of finer-grained calcareous sandstone. These shales have a thickness varying from a few feet to about 100 feet. The fauna is sparse and the fossils not well preserved. In the westward extension the rocks carry a number of species of pelecypods, brachiopods and cephalopods; but in the more eastern part the formation is quite barren and the above-mentioned forms are for the most part absent. Plant remains are not uncommon in the black shales and conodonts and fish plates occur. Among the fossils are the brachiopods *Orbiculoidea lodensis, Lingula spatula* and the main guide fossil *Schizobolus truncatus;* the pelecypods *Pterochaenia fragilis, Liorhynchus quadricostatus;* the gastropod *Euryzone* (*Pleurotomaria*) *rugulata;* the pteropod *Styliolina fissurella;* the cephalopods *Probeloceras lutheri* and *Bactrites aciculum.*

The *Portage beds* (Hall '40) received their name from Portageville on the Genesee river and now include the formations between the Genesee and the Chemung beds (Hall '43), though originally only the formations above the Gardeau were included in this term (figure 53). In western New York these formations are characterized

Figure 53 Upper Devonian rocks. Portage (Gardeau) beds in the Genesee gorge at Portage, Livingston county. (Photograph by J. A. Glenn)

by the Naples fauna; in central New York by the Naples-Ithaca fauna (the latter in Sherburne and Ithaca beds). In eastern New York the marine Sherburne and Ithaca beds carry the Ithaca fauna (marine), the Oneonta beds are nonmarine. The term *Naples beds* (Clarke '85) has been applied to the formations carrying the Naples fauna, an alien fauna with *Manticoceras* (*intumescens*) *pattersoni*. The Portage beds have an aggregate thickness of 1000 to 1500 feet, and as here defined begin with the Genundewa limestone. The *Genundewa limestone* (Clarke '03; Luther) is a thin band of impure limestone described as the "Styliola band" and also "Styliolina limestone" because of the immense numbers of the pteropod *Styliolina fissurella* occurring in it. It received its present name from the exposure at Genundewa point, Canandaigua lake. This limestone band has a thickness of eight feet more or less and is found from Cayuga lake valley westward to Lake Erie. Fossils are abundant in this formation, and besides those found in the Genesee black shale there occur other species characteristic of the later Naples beds. This limestone has also afforded many conodonts. Succeeding the Genundewa limestone are dark gray shales (12 to about 100 feet) with interstratified beds of black shales. This is the *West River shale* (Clarke and Luther '04) named from the West River valley section, Yates county. Calcareous concretions are common in these shales and a few thin flags of calcareous sandstones occur. In the Cayuga and Seneca lakes region the term has been used to embrace the beds between the Genundewa limestone and Cashaqua shale, that is, including the Middlesex (Portage) shale. Fossils are rare in the West River beds. Most of the fossils already listed

for the Genesee black shale occur; also the pelecypods *Lunulicardium curtum, Panenka* sp., and the crinoid *Melocrinus clarkei.* The *Standish flags and shales* (Clarke and Luther '04) are thin, uneven, bluish gray flags and olive shales, with a thickness not exceeding 15 feet, and representing the transition in west central New York "from the argillaceous shales of the West River beds into the arenaceous sedimentation characterizing, for the most part, the mass of the Portage strata." The name is from Standish gully, near Italy, Yates county, and the formation is a local one. The *Middlesex shale* (Clarke '03; Luther) was named from the occurrence in Middlesex valley, Yates county, and was at one time included in the upper Genesee beds. It was later called (Clarke '85) the "Lower black band" of the Portage. These are densely bituminous deposits (20 to 40 feet, more or less, in thickness), similar to the Genesee black shale and with a meager fauna showing affinities with that of the *Cashaqua shale* (Hall '40). These latter are light, soft, rather calcareous shales (50 to 125 feet, more or less) succeeding black shales and limited at the top by similar bituminous shales. They extend from Lake Erie to the Cayuga lake region where they become involved with the Sherburne flags(Ithaca fauna). In these soft shales the peculiar western Portage fauna (Naples) attained its culmination. In the midst of the Cashaqua shales in west central New York (Canandaigua lake region to Seneca lake) is a limestone lentil, the *Parrish limestone* (Clarke and Luther '04) characterized by a singular composition of greenish and reddish calcareous nodules and carrying an abundant goniatite fauna. In the recurrent beds of black shale above the Cashaqua, the

Rhinestreet shale (Clarke '03; Luther), the fauna is curtailed again. These shales, named from the section along Rhinestreet north of Naples, Ontario county, have a thickness of about 200 feet in the Lake Erie region, but thin eastward to Seneca lake valley where the thickness is two feet. This is the "Upper black band" of the Portage in older literature (Clarke '85). The *Hatch flags and shales* (Clarke '03; Luther) following are arenaceous beds (150 to 400 feet thick, more or less) named from the abundant exposures on Hatch hill at Naples, Ontario county. They are blue and olive shales with frequent thin layers of black shale and thin sandstone. There is a partial return to the conditions in the Cashaqua beds below, but fossils occur in very decreased numbers. There is an increase in the proportion of sand in the sedimentation eastward, and here there is evidence of alternations of the normal Naples fauna with the Ithaca fauna of central New York. The *Angola shale* (Clarke '03; Luther) and *Hanover shales* (Hartnagel '12; formerly Silver creek) farther west in Erie county have been considered as equivalents of the lower and upper parts of the Hatch shales. More recently (Chadwick '19) they have been traced continuously into the higher horizon of the Wiscoy shale. The *Grimes sandstone* (Luther '02) is a well-defined arenaceous band, with a thickness of 25 to 75 feet, composed of even layers of sandstone, some rather soft and shaly, others hard and calcareous. The name is derived from the exposure in Grimes gully near Naples, and the formation extends from Cayuga county to not far west of the Genesee valley. The eastern part of the formation (to Naples) shows an invasion of a brachiopod (Ithaca) fauna from the east. This formation marks

the upper limit of the Naples fauna in this section. The succeeding *Gardeau flags and shales* (Hall '40) consist of light bluish gray sandstones and flags separated by beds of blue, olive or black shales and are much like the Hatch shales and flags. The formation (about 400 feet thick), named from the old Indian reservation in the counties of Livingston and Wyoming, extends as far west as Lake Erie. Fossils are rare. Brachiopods of the Ithaca fauna occur in some of the sandstones, pelecypods and cephalopods of the Naples fauna in the soft shales. Eastward appear the *West Hill flags and shales* (Clarke '03) extending as far as Schuyler county, with a maximum thickness of 550 to 600 feet. They are named from West hill, near Naples, in Ontario county, and are in part the equivalent of the Gardeau. These beds are characterized by the Ithaca fauna, though representatives of both faunas occur. Above the Gardeau shales and flags occurs the *Nunda sandstone* (Vanuxem '42) with a thickness of 125 to 215 feet, named from the town of Nunda, Livingston county. This is the "Portage sandstone" of early reports. It consists of light blue-gray sandstone layers, some calcareous to a certain degree, some shaly, with intercalated beds of shale. Westward fossils are very rare and the formation barely reaches Lake Erie. There are a few representatives of the Gardeau fauna. Eastward the formation carries a Chemung fauna and is known as the *High Point sandstone* (Luther '02) from its occurrence at High Point, near Naples, Ontario county. This formation (85 to 100 feet thick) is known as far east as Chemung county. The *Wiscoy shale* (Clarke '99) succeeds the Nunda sandstone with a thickness of about 200 feet of shaly olive beds. The name is from

the exposures at the falls of Wiscoy creek at Wiscoy, Alleghany county. The fauna is a sparse one (Naples), both in species and individuals. Eastward the more sandy stratigraphic equivalent is the *Prattsburg sandstone* (Clarke '03) which carries a Chemung fauna. This formation received its name from Prattsburg, Steuben county, and has a thickness of 250 to 600 feet. It extends as far east as Chemung county.

In central New York the Cashaqua shale becomes involved with the Sherburne flags (its stratigraphic equivalent in the east) bearing the Ithaca fauna. The *Enfield shale* (Williams '06), with a thickness of 200 to 900 feet, constitutes the upper part of the original "Ithaca group" of Hall; the restricted Ithaca (80 to 500 feet) the lower part, beneath which is the Sherburne sandstone. The name is from Enfield in Tompkins county. The *Ithaca shale member* (Hall '39), named from Ithaca, Tompkins county, contains an abundant representation of a more or less modified Hamilton fauna, but westward it passes horizontally into beds with the Naples fauna. Farther east there is little evidence of the Ithaca fauna and the beds take on the lithologic character seen in the Oneonta, indicating different physical conditions during deposition. The *Sherburne flags* (Vanuxem '40) were named from Sherburne, Chenango county. These beds have a thickness of 185 to 250 feet. In central New York they rest upon the Genesee beds, in Otsego county upon the Tully limestone, in the east following the Hamilton beds and apparently extending into Pennsylvania. The best faunal development occurs in Otsego and Schoharie counties, fossils being rare farther southeast. In the east the upper beds have been considered contemporaneous with early

Ithaca beds in the central part of the State. Recent studies (Cooper '30) suggest that the Sherburne sandstone at its type locality and probably for some distance eastward is actually a clastic phase of the Tully, and that at least part of the Sherburne of the Schoharie valley is in reality of Hamilton age, representing the Moscow and at least a portion of the Ludlowville. The Sherburne flags are bluish, rather fine-grained sandstones alternating with smooth, greenish or olive colored shale. Typical marine fossils are absent from the typical Sherburne sands and shales. The Sherburne sandstone represents a bar formation, this bar acting as a barrier which separated the western fauna in central New York from the modified Hamilton fauna in the eastern area of the Atlantic. The *Oneonta sandstone* (Vanuxem '40), with a thickness of 2000 to 3000 feet, represents the uppermost Portage in the east (figure 1). The name is derived from exposures in Oneonta, Otsego county. These are red beds, a nonmarine deposit overlying the Ithaca beds from Chenango eastward, the basal portion probably being equivalent in time to the higher Ithaca beds of the central part of the State. The beds are quite unfossiliferous. They are characterized by the fresh or brackish water clam *Archanodon* (*Amnigenia*) *catskillensis* and a small crustacean has been reported. Plant remains as the club mosses *Archaeosigillaria* and *Protolepidodendron,* the tree fern *Archaeopteris* and the seedfern *Eospermatopteris* occur. The highest formation in the great Devonian outlier in Orange county, typically exposed in Skunnemunk mountain, is the *Skunnemunk conglomerate* (Darton '94) which extends south through Bellvale mountain into New Jersey. It has a thickness of 300 to 2500 feet,

and is thought to represent Portage time with the upper beds as late as the Catskill.

The *Naples fauna*, as stated in the general discussion above, is a western fauna which has afforded a strange association, particularly of bivalves. This fauna includes the crinoid *Melocrinus clarkei;* the coral *Aulopora annectens;* brachiopods as *Productella speciosa, Chonetes scitulus, Lingula triqueter;* pelecypods as *Lunulicardium ornatum, L. clymeniae, Loxopteria dispar, L.* (*Sluzka*) *intumescentis, Ontario halli, O. suborbicularis, Cardiomorpha obliquata, Paracardium doris, Buchiola retrostriata, Elasmatium gowandense;* gastropods as *Loxonema noe, Palaeotrochus praecursor, Phragmostoma incisum, Protocalyptraea marshalli, Bellerophon incisum;* cephalopods as *Manticoceras pattersoni, Tornoceras bicostatum, T. uniangulare, Probeloceras lutheri, Cyrtoclymenia neapolitana, Bactrites gracilior;* the conularid *Hyolithes neapolis;* the pteropods *Tentaculites gracilistriatus* and *Styliolina fissurella;* the crustaceans *Eleutherocaris whitfieldi* and *Spathiocaris emersoni.*

The *Ithaca fauna* is a modified Hamilton fauna and the similarity of the faunas is very striking. This fauna, like the Hamilton, is predominantly a pelecypod one. It includes brachiopods as *Leptaena rhomboidalis, Strophalosia truncata, Leptostrophia perplana* var. *nervosa, Atrypa reticularis, Chonetes lepidus, Cyrtina hamiltonensis, Rhipidomella vanuxemi, Spirifer mucronatus, S. mesastrialis, Reticularia laevis, Athyris spiriferoides* etc.; pelecypods as *Actinopteria eta, A. boydi, Grammysia subarcuata, G. bisulcata, Modiomorpha mytiloides, Goniophora subrecta, Cimitaria recurva, C. elongata, Cypricardella bellistriata, Paracyclas lirata, Leptodesma rogersi,*

Paleoneilo emarginata, Nuculites triqueter, Panenka retusa etc.; gastropods as *Straparollus hecale, Carinaropsis ithagenia, Bellerophon patulus* etc.; cephalopods as *Orthoceras leander, Spyroceras pertextum, Gomphoceras tumidum, Gephyroceras perlatum;* crustaceans as *Rhinocaris capsella,* and the trilobites *Phacops rana* and *Homalonotus* (*Dipleura*) *dekayi.*

The *Chemung beds* (Hall '39) were named from exposures in Chemung valley in the county of that name. In western New York the Chemung formation overlies the typical Portage beds, in central New York the Ithaca beds, farther east the Oneonta beds. In the eastern section through to Pennsylvania the fauna occurs sparsely and the formation becomes involved with the red beds of the Catskill formation which in the east overlies the Oneonta red beds and is the nonmarine equivalent of the marine Chemung beds to the west, representing Mississippian time in its upper portion. In the east the Chemung beds are undivided. In central New York this formation has been divided into the Cayuta shale member and the Wellsburg sandstone member with the Fall Creek conglomerate lentil at the top (Williams '06). The *Cayuta shale* member was named from exposures along Cayuta creek, in Schuyler, Chemung and Tioga counties. It has a thickness of 600 feet and carries the typical Chemung fauna. The *Wellsburg sandstone* above, typically exposed in the vicinity of Wellsburg, Chemung county, has a thickness between 400 and 800 feet and near the top contains a ten-foot lentil of conglomerate, the *Fall Creek conglomerate.* In western New York the Chemung formation has been divided into a number of members and the Dunkirk shale and Laona sandstone previously in-

cluded in the Portage beds have now been put under the Chemung (Chadwick '19). The Chemung group here begins with the *Dunkirk black shale* (Clarke '03; Luther), named from Dunkirk in Chautauqua county. The formation has a thickness of 50 to 100 feet. The sandstones in this black shale increase until east of the Genesee valley very little black shale remains in the lower 150 feet of arenaceous beds with full Chemung fauna, and these beds are called the *Canaseraga sandstone* (from Canaseraga; Chadwick '19). These sandstones include the layer termed *Longbeards Riffs sandstone* (Clarke '03; Luther), named from the riffs on the Genesee river in Allegany county, eight miles south of Portageville. The Dunkirk-Canaseraga beds are believed to correspond to the basal Cayuta shale in the Ithaca region. The *Gowanda beds* (for Portage preoccupied of Luther '03) named from Gowanda (Lodi), Cattaraugus county (Chadwick '19) everywhere directly overlie the Dunkirk or its Canaseraga equivalent, with a thickness of 250 to 500 feet. There is a persistent, but limited, Portage fauna yielding eastward to the lower Chemung fauna of the Cayuta shale into which these beds have been traced. The next shale member, the *Westfield shale* (Chadwick '19) is bounded below by the *Laona sandstone* and above by the *Shumla sandstone* (Laona and Shumla, Chautauqua county; Clarke '03; Luther). These shales, named from Westfield, Chautauqua county, are lithologically indistinguishable from the Gowanda beds and have a thickness of 120 to about 200 feet. Here, too, is a persistent Portage cephalopod fauna, yielding eastward wholly to Chemung brachiopods. These and the *Northeast shales*

(Chadwick '19) above merge eastward into the Wellsburg member in central New York. The Northeast shales ("Portage flags" of I. C. White), renamed from the township in Erie county, Pennsylvania, have in New York a thickness of about 400 feet. In their western expression they are practically barren, but eastward assume a fossiliferous character. Next to the Dunkirk black shale the most important horizon marker in this group in the western area is the next member, the *Cuba sandstone* (Williams '87) with a thickness of ten to 15 feet and carrying the *Spirifer disjunctus* fauna of the Chemung. The name is from Cuba village, Allegany county. This sandstone marks the upper limit of *Spirifer (Delthyris) mesacostalis* in New York State. It is followed by the 100 to 180 feet of *Volusia shales* (Chadwick '19; from Volusia, Chautauqua county), a fossiliferous continuation of the *Girard shales* of Pennsylvania. Above this occur beds including shales of a distinctly reddish or chocolate color, a continuation of the fossiliferous "Chemung beds" of Erie county, Pennsylvania, called the *Chadakoin beds* from exposures, at Jamestown, on the Chadakoin river, Chautauqua county. These beds lie above the true Chemung in the "Catskill." Their upper limit is at the base of the Panama conglomerate (lowest Mississippian), and they carry *Spirifer disjunctus.*

The Chemung fauna is a modified Ithaca-Hamilton fauna and is characterized by *Spirifer disjunctus.* The fauna is largely a brachiopod and pelecypod fauna and includes brachiopods as *Spirifer disjunctus, Spirifer mesacostalis, Cyrtia alta, Athyris angelica, Atrypa reticularis, A. hystrix, Schizophoria striatula, Camarotoechia*

orbicularis, Dalmanella leonensis, Productella hirsuta, Chonetes scitulus, Orthothetes chemungensis; pelecypods as *Pterinea chemungensis, Pterinopecten suborbicularis, P. crenicostatus, Aviculopecten duplicatus, Lyriopecten magnificus, Lunulicardium acutirostrum, Mytilarca chemungensis, Grammysia communis, Sphenotus contractus, Leptodesma longispinum;* gastropods as *Loxonema laxum, Euomphalus tioga, Bellerophon maera;* cephalopods as *Orthoceras expositum, Poterioceras nasutum, Sandbergeroceras chemungense;* crustaceans as *Pephricaris horripilata.* Remains of fish as *Onychodus hopkinsi, Dinichthys curtus* occur in these beds. Sponges (as *Hydnoceras tuberosum* and *Thysanodictya apleta*) are locally abundant.

The *Catskill beds* (Mather '40) receive their name from the Catskill mountains and have their greatest development in Greene county. They consist of sandstone, shales and conglomerates, chiefly red, with a thickness up to 3000 feet in New York State. They are a nonmarine facies of the Upper Devonian and represent in the east the time equivalent of the Chemung beds. In the east they rest upon the Oneonta beds and toward the central part of the State upon the Portage. The red Catskill beds spread westward and replace the marine Chemung beds, continuing into Mississippian time. These beds are characterized by the fresh-water mussel, *Archanodon catskillensis.* Fish remains such as *Holoptychius americanus, Bothriolepis leidyi* etc. occur, and the eurypterid *Stylonurus excelsior* came from these beds (Andes, in the Catskills).

The *Rensselaer grit* (Dale '93) is an outlying area of grit in Rensselaer county resting unconformably on the

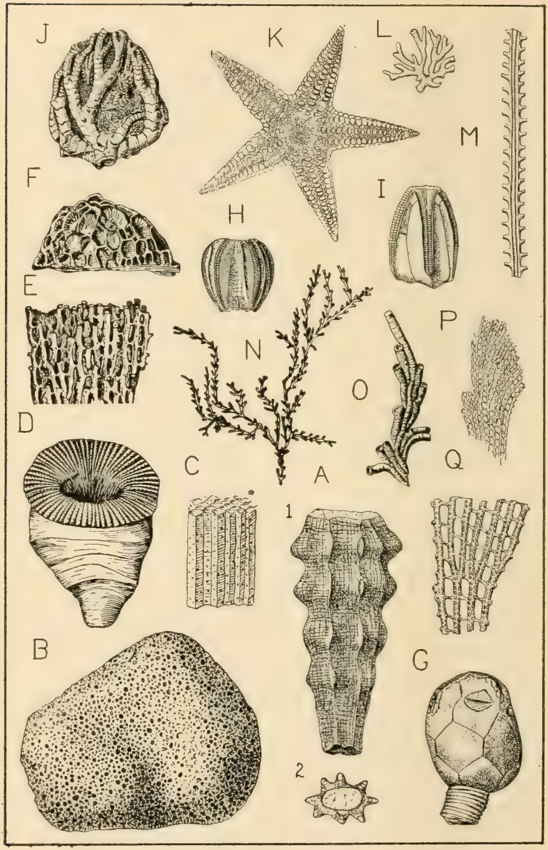


Figure 54 Devonian fossils. (Sponge, *A;* corals, *B-F;* echinoderms, *G-K;* bryozoans, *L-Q*). *A* 1, 2 *Hydnoceras tuberosum,* x½. *B, C Favosites helderbergiae,* x½, with enlargement of corallites. *D Heliophyllum halli,* x½. *E Syringopora hisingeri. F Pleurodictyum styloporum. G Lepocrinites (Lepadocrinus) gebhardi,* x¾. *H Elaeocrinus elegans. I Granatocrinus leda. J Taxocrinus lobatus,* x½. *K Devonaster eucharis,* x½. *L Thamniscus variolata. M Pinnatopora carinata,* x4½. *N, O Hederella canadensis,* with enlargement, x6. *P, Q Fenestella crebipora,* x1, with enlargement.

upturned edges of older beds (Cambrian to Ordovician). It has been correlated with the Shawangunk grit and also the Oneida conglomerate, but recent studies (see Ruedemann '30) have shown it to be of Upper Devonian (Catskill) age.

Characteristic Devonian sections may be seen in the Helderberg-Catskill area and in the Lake Erie area. In the Kingston region of the former area the Coeymans limestone lies above the Manlius (Upper Manlius or Keyser, mainly). Then follow in succession the New Scotland, Becraft and Alsen limestones, the Port Ewen beds, the Oriskany (Glenerie) limestone, Esopus grit, Onondaga limestone, Hamilton beds (Marcellus, Mount Marion, Ashokan), Oneonta series, Catskill shales and sandstones. In the Indian Ladder region, Helderberg mountains, there are exposures showing formations from the Upper Ordovician to the Middle Devonian (figure 52). In the Lake Erie section, the Onondaga limestone rests unconformably upon the Cobleskill and is followed in succession by the Hamilton (incl. Marcellus) beds, the Tully limestone, the Genesee beds, the Portage beds (which are replaced eastward by the Ithaca beds) and finally the Chemung beds.

The fossils. Characteristic fossils found in Devonian formations are illustrated in figures 54 to 59 and are listed below.

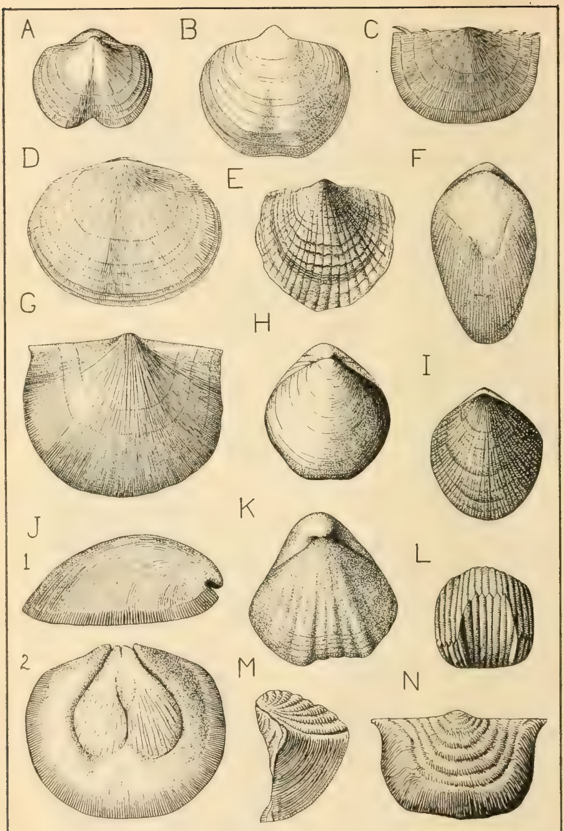


Figure 55 Devonian brachiopods. *A Schizophoria striatula*, x¾. *B Athyris spiriferoides*, x¾. *C Chonetes coronatus*. *D Rhipidomella oblata*, x¾. *E Atrypa spinosa*, x¾. *F Rensselaeria ovoides*, x½. *G Stropheodonta demissa*, x¾. *H Meristella laevis*, x¾. *I Atrypa reticularis*, x¾. *J* 1, 2 *Hipparionyx proximus*, x½. *K Sieberella coeymanensis*, x¾. *L Uncinulus mutabilis*, x¾. *M, N Leptaena rhomboidalis*, x½.

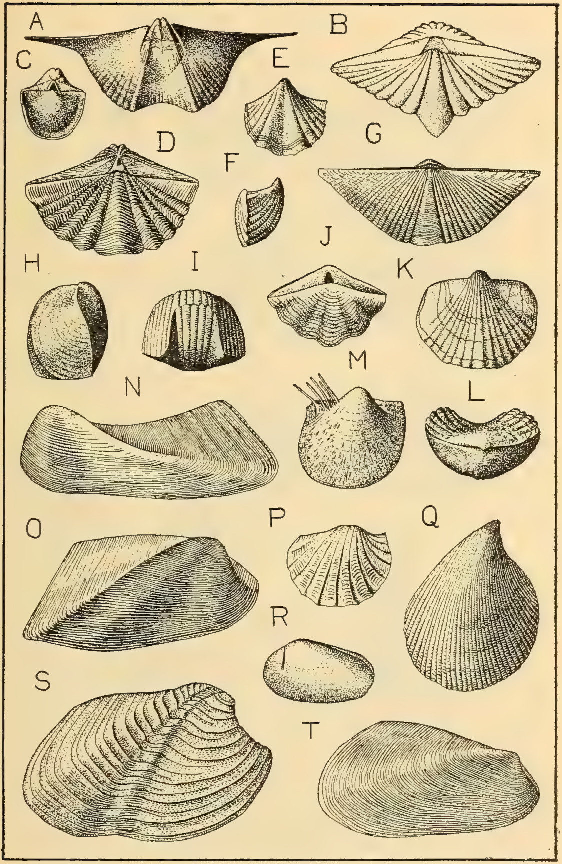


Figure 56 Devonian brachiopods and pelecypods. (*Brachiopods, A-M*). *A Spirifer disjunctus*, x½. *B S. murchinsoni*, x¾. *C Ambocoelia umbonata*. *D Spirifer perlamellosus*, x¾. *E, F Cyrtina hamiltonensis*. *G Spirifer mucronatus*, x¾. *H, I Hypothyris cuboides* (*Hypothyridina venustula*), x¾. *J Spirifer raricostatus*. *K Tropidoleptus carinatus*, x¾. *L Eatonia medialis*, x½. *M Productella hirsuta*, x¾. *N Cimitaria angulata*, x½. *O Goniophora hamiltonensis*, x¾. *P Buchiola retrostriata*, x4½. *Q Lunulicardium acutirostrum*, x¾. *R Nuculites oblongatus*, x¾. *S Grammysia bisulcata*, x¾. *T Modiomorpha concentrica*, x½.

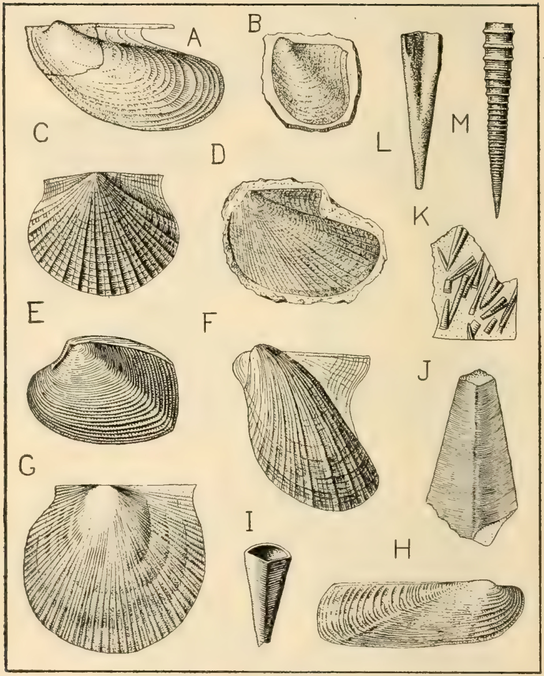


Figure 57 Devonian fossils. (Pelecypods, *A–H;* conularids, *I, J;* pteropods, *K–M*). *A Leptodesma longispinum*, x¾. *B Megambonia* (?) *aviculoides*, x¾. *C Aviculopecten ornatus*, x¾. *D Actinopteria textilis*, x¾. *E Cypricardella bellistriata*, x¾. *F Pterinea flabellum*, x½. *G Pterinopecten suborbicularis*, x¾. *H Orthonota undulata*, x½. *I Hyolithes neapolis*, x3½. *J Conularia undulata*, x⅓. *K Styliolina fissurella*, x3. *L* The same, x6, *M Tentaculites bellulus*, x2.

Devonian Fossils

CORALS

Favosites helderbergiae (L. Held.)*
Heliophyllum halli (Ham.)
Pleurodictyum styloporum (Ham.)
Syringopora hisingeri (On.)

SPONGE

Hydnoceras tuberosum (Chem.)

ECHINODERMS

Devonaster eucharis (Ham.)
Elaeocrinus elegans (Ham.)
Granatocrinus leda (Ham., Tully)
Lepocrinites gebhardi (Coey.)
Taxocrinus lobatus (Ham.)

BRYOZOANS

Fenestella crebipora (L. Held.)
Hederella canadensis (Ham.)
Pinnatopora carinata (Ham.)
Thamniscus variolata (L. Held.)

BRACHIOPODS

Ambocoelia umbonata (Marc.-Chem.)
Athyris spiriferoides (On., Ham.)
Atrypa reticularis (Sil., Dev.)
Atrypa spinosa (On.-Chem.)
Chonetes coronatus (Ham.)
Cyrtina hamiltonensis (On.-Port.)
Eatonia medialis (Held.)
Hipparionyx proximus (Orisk.)
Hypothyris cuboides (Tully)
(= *Hypothyridina venustula*)
Leptaena rhomboidalis (N.S. type; Ord.-Miss.)
Meristella laevis (Held.)
Productella hirsuta (Chem.)
Rensselaeria ovoides (Orisk.)
Rhipidomella oblata (Held.)
Schizophoria striatula (Mid. & Up. Dev.)
Sieberella coeymanensis (Coey.)
Spirifer disjunctus (Chem.)
Spirifer mucronatus (Marc.-Chem.)
Spirifer murchisoni (Orisk.)
Spirifer perlamellosus (Held.)
Spirifer (Delthyris) raricostatus (On.)
Stropheodonta demissa (Ham.)
Tropidoleptus carinatus (Marc., Ham.)
Uncinulus mutabilis (Coey.)

PELECYPODS

Actinopteria textilis (Held.)
Aviculopecten ornatus (Ham.)
Cimitaria angulata (Chem.)
Cypricardella bellistriata (Ham.-Up. Dev.)
Goniophora hamiltonensis (Ham.)
Grammysia bisulcata (Ham.)
Leptodesma longispinum (Chem.)
Lunulicardium acutirostrum (Gen.-Chem.)
Megambonia (?)aviculoidea (Held.)
Modiomorpha concentrica (Ham.)
Nuculites oblongatus (Ham.)
Orthonota undulata (Ham.)
Pterinea flabellum (On., Ham.)
Pterinopecten suborbicularis (Chem.)

GASTROPODS

Bembexia sulcomarginata (Ham.)
Bucanopsis leda (Ham.)
Diaphorostoma lineatum (On., Ham.)
Euomphalus disjunctus (Becr.)
Euryzone lucina (On., Ham.)
Loxonema noe (Port.)
Palaeotrochus praecursor (Port.)
Platyceras spirale (Held.)
Platyceras ventricosum (Held.)

CEPHALOPODS

Geisonoceras subulatum (Ham.)
Manticoceras pattersoni (Port.)
Nephriticeras buccinum (On.-Ham.)
Trochoceras discoideum (Scho.)
Tornoceras bicostatum (Port.)

CONULARIDS

Conularia undulata (Ham.)
Hyolithes neapolis (Port.)

PTEROPODS

Styliolina fissurella (Marc.-Up. Dev.)
Tentaculites bellulus (Ham.)

TRILOBITES

Cryphaeus boothi (Ham.)
Dalmanites nasutus (Held.)
Dalmanites pleuroptyx (Held.-On.)
Dipleura dekayi (Ham.)
Phacops rana (Ham., On.)
Proëtus rowi (Ham.)
Terataspis grandis (Scho.)

OTHER CRUSTACEANS

Echinocaris punctata (Ham.)
Pephricaris horripilata (Chem.)

* Agon.= Agoniatite l.s.; Becr. = Becraft; Chem. = Chemung; Coey. = Coeymans; Dev. = Devonian; Gen. = Genesee; Ham. = Hamilton; Held. = Helderbergian; Kalk. = Kalkberg; Marc. = Marcellus; Miss. = Mississippian; N.S. = New Scotland; On. = Onondaga; Ord. = Ordovician; Orisk. = Oriskany; Port. = Portage; Scho. = Schoharie; Sil. = Silurian.

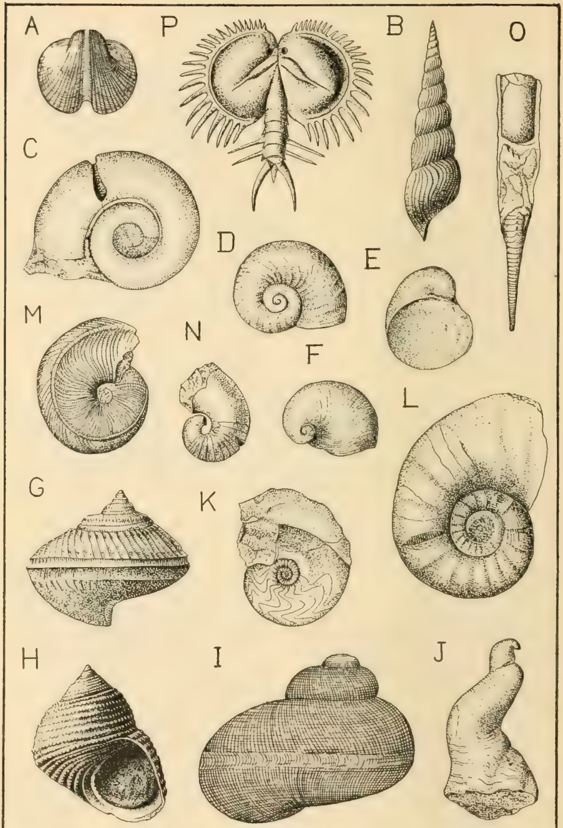


Figure 58 Devonian fossils. (Gastropods, *A–J*; cephalopods, *K–O*; crustacean, *P*). *A Bucanopsis leda*, x½. *B Loxonema noe*, x2¼. *C Euomphalus disjunctus*, x½. *D Diaphorostoma lineatum*, x¾. *E, F Platyceras ventricosum*. *G Bembexia sulcomarginata*, x¾. *H Paleotrochus praecursor*, x2. *I Euryzone lucina*, x2/3. *J Platyceras spirale*, x½. *K Manticoceras pattersoni (intumescens)*, x½. *L Trochoceras discoideum*. *M Tornoceras bicostatum*, x½. *N Nephriticeras buccinum*, x¼. *O Orthoceras (Geisonoceras) subulatum*, x1/3. *P Pephricaris horripilata*, x¾.

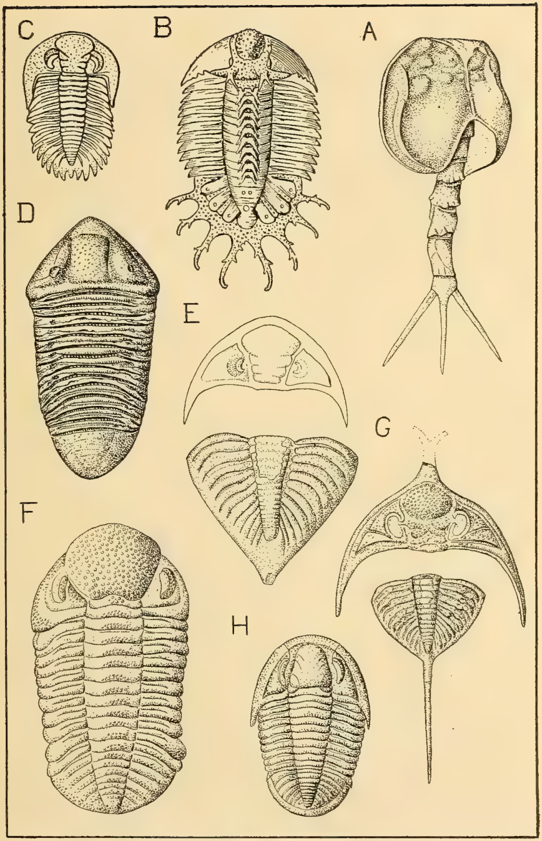


Figure 59 Devonian crustaceans. (*B–H,* trilobites). *A Echinocaris punctata,* x¾. *B Terataspis (Lichas) grandis,* x1/16 (after Schuchert). *C Cryphaeus boothi. D Homalonotus (Dipleura) dekayi,* x⅜. *E Dalmanites pleuroptyx,* x½. *F Phacops rana,* x½. *G Dalmanites nasutus,* x⅓. *H Proëtus rowi.*

Literature. For the general discussion of the Devonian period the same textbooks are recommended as for the previous chapters; also Schuchert ('10), Ulrich ('11), Ulrich and Schuchert ('02), Willis and Salisbury ('10) and Weller ('10).

For the New York formations Miller ('24) is recommended for a general survey and many references. Among other State Museum publications are Chadwick ('24), Clarke ('96, '00, '01a, b, '03a, '08–'09), Clarke and Luther ('04, '05a, b, '08), Darton ('94a, b, c), Grabau ('98, '03, '06), Hartnagel ('12), Hopkins ('14), Loomis ('03), Luther ('06a, b, '09, '11, '14), Prosser ('96, '99a, b, '00), Ruedemann ('30), Shimer ('05). Articles on New York formations printed elsewhere have been written by Chadwick ('08), Cleland ('03), Cooper ('30), Dale ('04), Fairchild ('28), Grabau ('17, '19), Prosser ('03), Schuchert ('00), Williams ('06, '07), Williams and Kindle ('05) and Williams, Tarr and Kindle ('09).

Mississippian, Pennsylvanian, Permian Periods

The term *Carboniferous* was formerly applied to the system of rocks above the Devonian from the quantities of coal (carbon) occurring in the rocks of that period. The system then included the Lower Carboniferous (Mississippian), the Upper Carboniferous (Pennsylvanian) and the Permian, which are now regarded as separate systems. Some geologists believe that there is evidence to show that there is no true Permian in this country, that the Lower Permian beds belong with the Upper Carboniferous or Pennsylvanian and that the Upper Permian belongs with the following Mesozoic era. The name *Mississippian* (Winchell, '70) was applied because of the marked development of these rocks in the Mississippi

valley; the name *Pennsylvanian* (H. S. Williams, '91) from the marked development in the Pennsylvanian area. In Europe the terms Lower and Upper Carboniferous continue to be largely used for the two systems. The name Permian was proposed by Murchison (1841) from the Russian Gouvernement of Perm where beds of this age were found extensively. The "Carboniferous" systems together constitute about one-tenth (9 per cent of geologic time).

Geology. The Mississippian system is set off from the Devonian below by a complete break due to the marked retreat of the seas at the end of that period. Submergence started again in early Mississippian or Waverlyan time and reached its maximum extent toward the latter part of the Waverlyan. At the close of Waverlyan time there was a widespread withdrawal and marked change in seaways. The seas of late Mississippian (Tennessean) began a renewed spread, reaching their maximum about the middle of this time, though the continental seas were never as extensive as in early Mississippian times. The land area of Appalachia still existed. The deposits in the Appalachian trough were derived from this land area and consisted for the most part of coarse sands and muds, marked with sun cracks, ripple marks etc. that indicate an arid or semi-arid climate. In the Acadian province was another basin in which wholly continental deposits were laid down in early Mississippian. In late Mississippian time conglomerates, sands and muds were deposited in seaways, the presence of gypsiferous beds indicating that bodies of sea water were occasionally shut off. During the Mississippian the interior sea expanded widely and probably covered nearly the whole

of the Great Plains region and most of the land areas of the west and southwest from, and including, Mexico to the Arctic. Shales with limestone and gypsum in the Michigan area likewise indicate a dry climate and times when the bays of the sea were converted into salt lakes. In the Appalachian area the clastic sediments have a maximum thickness of about 4000 feet. Here occur the oldest American coal beds and the Mississippian has therefore sometimes been termed the "false Coal Measures." The deposits of the interior sea are largely limestones and have a thickness between 1000 and 2000 feet. In the Cordilleran sea limestones were deposited with maximum thicknesses between 1500 and 2500 feet. In the Acadian province clastic deposits have an aggregate thickness of 4000 feet to 6000 feet, with extensive sheets of igneous rocks at the top of the series. At the close of the Mississippian widespread uplift and withdrawal of the sea resulted in a general unconformity between this and the next period, the Pennsylvanian. Folding occurred in several parts of North America, as the southern Appalachian and the Nova Scotia-New Brunswick areas.

Though coal accumulation had begun in the Mississippian the period of greatest accumulation was in the Pennsylvanian, also known as the *Coal Measures*. The period is characterized by great coal-making swamps. In certain areas the seas were most oscillatory, local warpings resulting in periodic shallow water conditions. In the Appalachian trough and in the central interior sea there are alternations of marine deposits with coal accumulations. In the Appalachian trough sediments carried in by the streams brought about intermittent sinking, and at intervals this area was slightly above sea level and sediments were continental. At other times marine wa-

ters encroaching upon the land formed the vast brackish-water swamps in which thick coal beds were laid down. Coal beds also accumulated in fresh water above but near sea level. At the same time marine conditions prevailed in the west and southwest with the deposition of limestones and shales. The thickest Pennsylvanian deposits occur in the Ouachita mountains in Arkansas and Oklahoma and in Alabama, where there is a maximum thickness of 9000 feet, mostly coarse clastic material. In the Maritime Provinces of Canada continental deposits to a thickness of 10,000 to 13,000 feet represent this period. In western United States in Oklahoma, Texas and the southern part of the Great Plains country red beds and gypsum and potash deposits appear in the higher series of rocks, indicating an arid climate and the contraction of seas toward the close of the Pennsylvanian or even in Permian time. The close of the Pennsylvanian is marked by a general retreat of the seas which continued into the Permian. The late Mississippian and the Pennsylvanian were times of crustal movement. High mountains came into being in eastern Canada and the southern Appalachian area at the close of the former period and these risings continued in the Pennsylvanian. The ancestral Southern Rockies also came into being. Beds of iron ore, but none of commercial value, are associated with the coal of the Pennsylvanian and also oil and gas abound in certain areas, as Oklahoma.

In North America the Permian is a continuation of the Pennsylvanian and its importance consists in that it is a transition period between the Paleozoic and the Mesozoic eras. Deposits of this age (Dunkard group) are represented in the east in southwest Pennsylvania and along the Ohio river in Ohio and West Virginia by sandstones,

shales, limestones and a few beds of coal, with a thickness of 1000 feet. In the Maritime Provinces of Canada red shales and sandstones indicate inclosed basin conditions at this time. Through the west and the southwest the shallow seas of the early part of the period withdrew in the latter part leaving salt lakes in which deposition of salt and gypsum took place, which together with the sun-cracked and ripple-marked red beds indicate an arid climate. There is evidence of widespread glaciation in the Permian, probably greater than that of our "Great Ice Age." Permian glacial deposits have been found in India, South Africa, Australia, Germany, England, Brazil, Argentina and possibly Massachusetts in North America. The close of the Paleozoic is marked by mountain-making disturbances of almost worldwide occurrence, beginning with late Mississippian. This disturbance reached its culmination at the end of the Permian when the deposits of the Appalachian geosyncline were elevated into the Appalachian mountains. The folding extended in a northeast-southwest direction from Nova Scotia southward into Alabama and the Ouachita mountains of Arkansas.

Life. Mississippian life was diversified. The great variety and richness of the *crinoids* is noteworthy, and great thicknesses of limestone were built up from their remains. *Blastoids* (*Pentremites*) reach their culmination here and are the guide fossils to the marine deposits. In these rocks also are found the characteristic *echinoid* (*Melonechinus*) and a peculiar bryozoan (*Archimedes*) with a screwlike axis. *Brachiopods* are abundant, the genus *Productus* being characteristic of all three Carboniferous periods. *Bryozoans* and *cup corals* are also

abundant. Large, shell-feeding *sharks* developed rapidly and many kinds of amphibians existed. The plant life was much as in the Pennsylvanian.

The marine life of the Pennsylvanian period, like that of the preceding, was varied. The spiny *brachiopods* (*Productus*) were abundant and were the commonest of the shelled animals, though *pelecypods* were becoming more and more abundant. *Foraminifera* for the first time were abundant and varied (*Fusilina,*) as also in late Mississippian. While brachiopods were declining the goniatite and ammonoid *cephalopod stocks* were rapidly developing. *Trilobites* and *eurypterids* became extinct in the Pennsylvanian. *Land snails* appear in this period. Insects are present in giant form and because of the abundance of cockroaches the Pennsylvanian is known as the *Age of Cockroaches. Scorpions* and *spiderlike animals* are found and *myriopods* or thousand-legged worms are plentiful. Among the *fishes* only sharks and typical ganoids were important, and the number of sharks had become very small before the close of the Pennsylvanian. Among land animals there were many kinds of *amphibians* inhabiting the coal swamps, and *reptiles* appeared in the Upper Pennsylvanian. The *land plants* of the Carboniferous, particularly the Pennsylvanian or Coal Measures, consisted of ferns (including tree ferns), seed ferns, club mosses or lycopods, horsetails (calamites) and some gymnosperms (*Cordaites* etc.). (See part 1)

The marine life of the Permian is a modification of Pennsylvanian faunas. *Insects* are greatly changed in this period. They have become smaller and more modern. The *reptiles* of the Permian are even more varied than the *amphibians.* America has by far the richest and most varied fauna of Permian vertebrates.

Climate. The life of the Mississippian indicates warm equable marine waters. In the early part of the period warm and moist conditions on the land are indicated, but in the latter part of the period semi-arid and even arid conditions prevailed, and toward its close the climate became cool. The cooler climate of early Pennsylvanian time rapidly gave place to warm, equable and humid conditions, as indicated by the luxuriant growth of the coal plants. Semi-arid conditions developed in later Pennsylvanian time and continued into the Permian, forcing the development of seed plants. In the Permian deserts existed in many places including western North America, as testified by sun-cracked and ripple-marked deposits, red beds and salt and gypsum deposits.

New York formations. Carboniferous strata are only sparingly represented in New York State, outlying masses of oldest Mississippian unconformably overlain by oldest Pennsylvanian occurring in southwestern New York, in Allegany and Cattaragus counties. The extent of the Carboniferous seas over southern New York is not known. Permian rocks are not present at all in this State. The formations are as follows:

MISSISSIPPIAN SYSTEM	PENNSYLVANIAN SYSTEM
Bradford	**Pottsville**
Knapp beds	Sharon shale
Oswayo shale	Olean conglomerate
Cattaraugus beds	
Kilbuck conglomerate	
Salamanca conglomerate	
Wolf Creek conglomerate	

The *Cattaraugus beds* (Glenn '03; Fuller) were named from exposures in Cattaraugus county and include sandstones and conglomerates with minor amounts of bright

red argillaceous shales, with an aggregate thickness of 300 to 500 feet. At the base is the *Wolf Creek Conglomrate* lentil (Williams '87) named from Wolf creek, Allegany county, eight miles east of Olean, which marks the base of the Mississippian and is underlain by the Chemung. The pebbles in this conglomerate are mostly of vein quartz and predominantly flat or discoidal. The bed has a thickness varying from a few inches to 20 feet. Above this are 300 to 350 feet of interbedded green or bluish shales and fine-grained, greenish gray, thin-bedded micaceous sandstones, with lenses of bright red shales. The Wolf Creek conglomerate has a marine fauna, the red shales yield few or no fossils showing that they were deposited under conditions unfavorable to life. The Cattaraugus beds fade to the south in Pennsylvania into the Conewango beds, assuming more and more the full marine facies that is characteristic farther west. Above the red shale, in about the middle of the Cattaraugus formation, occurs the *Salamanca conglomerate* (Carll '83), named from the village of Salamanca in Cattaraugus county. It varies from a hard gray sandstone to a quartz pebble conglomerate with pebbles distinctly flattened and has a thickness from a few inches to 40 feet. In New York it is not found outside of Cattaraugus county, but it has an extensive distribution in Pennsylvania. The names "Panama," "Pope Hollow," "Wrightsville" and "Tuna" have been applied to this conglomerate. The *Panama conglomerate* (Carll '80) was named from its occurrence at Panama, in Chautauqua county and has a thickness up to 69 feet, and, while formerly correlated with the Salamanca, is now believed to belong to the horizon of the Wolf Creek conglomerate. Fifty to 70 feet above the Salamanca is a third conglomerate lentil, the

Kilbuck conglomerate (Glenn '03) named from the occurrence at Kilbuck, near Salamanca in Cattaraugus county. This conglomerate is not over ten to 15 feet thick and has much the same flat pebble character as the underlying Salamanca. This third conglomerate is followed by a variable thickness of shale. The probable occurrence of an unconformity at the top of this formation has been suggsted (Glenn).

The *Oswayo beds* (Glenn '03; Fuller) are olive-green to rusty colored sandy shales with here and there thin layers of sandstone with limonitic seams or incrustations. These greenish limonitic shales have a thickness of 160 to 250 feet. Conditions were favorable to the existence of life when these shales were deposited and there is a fairly good representation of marine invertebrates, the brachiopod *Camarotoechia allegania* being characteristic and serving as an excellent horizon marker. The Oswayo beds were named from Oswayo creek in Cattaraugus county.

The *Knapp beds* (Glenn '03) follow with a thickness of 60 to 105 feet and consist of two beds of conglomerate with interbedded shales. The formation has the stratigraphic position of the Subolean of Pennsylvania. It is not found east of Knapp creek station, Cattaraugus county, from which the name is derived, but is probably the equivalent eastward of grits and shales beneath the Olean. The shales of this formation are sandy and olive-green or rusty brown and in several places marine invertebrates have been found. The coarser part of the formation is loosely cemented conglomerate, with flattened quartz pebbles, frequently limonitic and fossiliferous in most places.

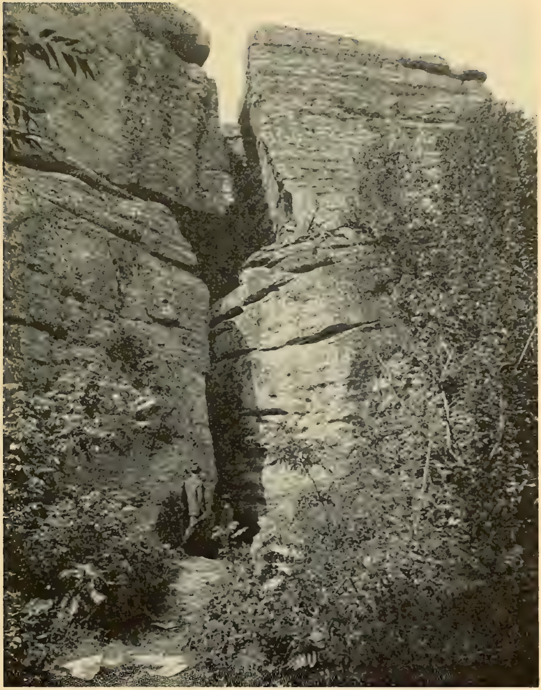


Figure 60 Pennsylvanian rocks. Olean conglomerate. "Rock City," Olean, Cattaraugus county.

The Pennsylvanian system is represented by the Olean conglomerate and Sharon shale of Pottsville age. The *Olean conglomerate* (Lesley '75) is a massive round-pebbled conglomerate, varying quite rapidly in texture both horizontally and vertically and with a thickness of 50 to 90 feet. It is widely known because it forms the "Rock City" southwest of Olean in Cattaraugus county (figure 60). Here, as at Little Genesee and a few other places in southwestern New York, it caps the highest hills (just north of the Pennsylvania state line). Plant remains of Pottsville age are found in this bed. Overlying the Olean conglomerate at "Rock City" is a very small, thin patch of sandy, ferruginous shales, the *Sharon shale* (Rogers '58). A thin coal bloom in connection with this was reported some years ago as disclosed in grading a road, indicating a thin streak of coal in the shale, but no coal of value need be looked for in New York. This shale is the highest member of the Paleozoic system in New York State.

The Fossils. As pointed out above some of these post-Devonic beds in New York State are fossiliferous, others are practically barren. Chemung types continue into these beds and Mississippian types appear. A study of the fossil faunas of the Olean Quadrangle (Butts '03) has brought out the fact that of 128 species collected 60 species occurred below the Wolf Creek conglomerate only, 59 species above the same horizon only. The characteristic fossils of this formation in this area are species of the peculiar pelecypod genus *Ptychopteria* elsewhere unknown. The brachiopod *Oehlertella pleurites* ranging through the Cattaraugus occurs also in the Cuyahoga formation of early Mississippian age in Ohio (Butts). The brachiopod *Camarotoechia allegania* is highly characteristic of the Oswayo shales.

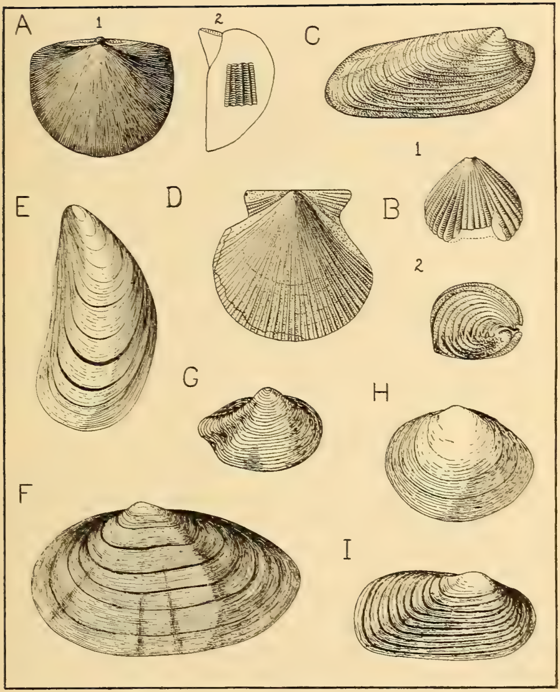


Figure 61 Mississippian and Pleistocene fossils. (Mississippian, *A–D;* Pleistocene, *E–I*). Brachiopods: *A* 1, 2 *Orthothetes crenistria,* x¾, with lateral view and surface enlargement; *B* 1, 2 *Camarotoechia allegania,* x¾, dorsal valve and internal mold of entire specimen. Pelecypods: *C Sphenotus aeolus,* x1; *D Crenipecten winchelli,* x1; *E Mytilus edulis,* x½; *F Mya arenaria,* x½; *G Yoldia arctica,* x1; *H Macoma groenlandica* (*balthica*), x1; *I Saxicava rugosa,* x1.

The fauna of the Knapp bed includes, in addition to the Devonian survivor *Spirifer disjunctus,* several species of *Leptodesma, Rhynchospira scansa and Athyris polita,* probably restricted to this horizon, and such representatives of basal Mississippian (Kinderhook) genera as *Productus, Syringothyris* and *Shumardella.* The Mississippian age of the Knapp can not be doubted. Above this fauna remains of the tree fern *Archaeopteris obtusa* occur well up toward the bottom of the Pottsville (Butts).

Literature. For the general discussion of the period are recommended the textbooks suggested for the preceding periods, also Schuchert ('10) and Ulrich ('11). Among other papers that may be consulted are Butts ('03), Carll ('90), Chadwick ('24), Clarke ('03), Glenn ('03), Hartnagel ('12), Lobeck ('27) and Williams ('87).

MESOZOIC ERA

The Mesozoic era includes formations that were among the first of the stratified rocks known to geologists. The name, meaning "middle life," was given to this group of formations in comparatively recent times. Mesozoic rocks were first studied in greatest detail in England. The era covers about one-tenth (11 per cent) of geologic time and includes the Jurassic, Triassic and Cretaceous periods, the last named comprising the Lower Cretaceous or Comanchean and the Upper Cretaceous or Cretaceous proper.

Triassic Period

The name Trias was applied to a group of three formations in northern Germany in contrast to a twofold series (the Permian) below. From this the name Triassic gradually came into use. As a result of the Appalachian

revolution the area of the State of New York was raised well above sea level and the only representation of rocks of this period in the State is a remarkable series of non-marine strata, the Newark series, in Rockland county and Staten Island. These deposits of Upper Triassic age were laid down in a series of troughlike depressions running roughly parallel with the main axis of the Appalachian range from Nova Scotia to North Carolina and lying between it and old Appalachia. One of these troughs occupied the area of the Connecticut valley; another extended from Rockland county into northern New Jersey, thence through northeastern Pennsylvania and Maryland into Virginia; smaller ones occupied the Virginia-North Carolina area.

There is a complete absence, so far as known, of marine Triassic sediments in the eastern half of North America. The coast line was farther to the east and the lands were undergoing erosion. The climate was arid or semi-arid. The continental deposits in the troughlike depressions accumulated to great thickness; and in them are occasionally found fish and plant remains and abundant fossil footprints, though fossils are rare. During the deposition of these sediments igneous activity took place, great thicknesses of lava were poured out, dikes and sills were intruded, and in places there was volcanic action. Such a sheet of lava, 300 to 850 feet thick, now forms the Palisades of the Hudson. Such lavas in the Triassic sediments, through faulting and subsequent erosion, have been responsible for the hills and mountains of the Connecticut valley, New Jersey etc.

In the western interior there are red beds of this age which were deposited in fresh water or salt water lakes or were of eolian origin. Along the Pacific coast a nar-

row bay reached from California to Wyoming early in the period and later spread along the coast northward to and including part of Alaska. Small areas in Mexico were under water. In these waters marine deposits were laid down.

The *Newark series* (Redfield '56) found in New York was named from exposures about Newark, New Jersey. These beds are of continental origin and were deposited in Upper Triassic times. Some even believe that the deposition continued into early Jurassic time. In New Jersey this series has been divided into three divisions, two of which the *Stockton beds* and the *Brunswick beds* (Kümmel '97) have been recognized in Rockland county. Three diabase areas outcrop in these beds, the *Palisade diabase,* which represents a great sill or sheet of igneous rock intruded near the close of the period, forming the Palisades of the Hudson. The Newark series has a thickness of 10,000 to 15,000 feet. Surfaces are marked with sun cracks, raindrop pits, ripple marks and remains and footprints of land reptiles, all features indicating deposition in very shallow water, flood plains, lakes etc. Remains of small dinosaurs have been found in Triassic rocks of the east, and recently a specimen was found in the Newark beds along the lower Hudson.

Jurassic Period

Rocks of this period do not occur in New York State. The area during this period was undergoing erosion so that by the end of the period this region and the entire Atlantic slope had been worn down practically to peneplane conditions. Indeed, there was extensive erosion throughout eastern United States during the Jurassic, as

the emergence of the continent continued from the Triassic; and there were no deposits except perhaps freshwater deposits in Maryland along the Potomac river and marine deposits in Mexico where the present Gulf of Mexico had extended westward. In the western interior no early Jurassic deposits are known. Later in the period a shallow arm of the sea extended from Alaska as far south as Utah and as far east as South Dakota but was soon drained through elevation of the land. Another area of deposition was in the great western geosyncline along the present Pacific coast. At the close of the period the enormous accumulation of sediments in this trough (Paleozoic, Triassic and Jurassic) were raised into the Sierra Nevada mountains, and about at the same time the growth of the Coast and Cascade ranges and the Klamath mountains was started.

The Jurassic period received its name from the occurrence of rocks of this age in the Jura mountains.

Cretaceous Period

The Cretaceous period or "Age of Chalk" received its name from the conspicuous chalk (Latin, *creta*) deposits of this time.

No marine deposits of the Lower Cretaceous or Comanchean occur along the Atlantic coast, but there are deposits of gravel and clays laid down as deltas and flood plains or in marshes or shallow lakes which extend from Martha's Vineyard, Mass., to Georgia. There was an expansion of the Gulf of Mexico westward and northwestward, covering large areas of Mexico, Texas and New Mexico, in which marine deposits were laid down. In the western interior only nonmarine beds (sometimes with coal) occur, and on the Pacific coast deposition took

place in narrow strips along the present California coast area and along the present coast from British Columbia northwards into Alaska. The Upper Cretaceous was a time of great subsidence. The sea spread over the coastal plains of the Atlantic and Gulf states and portions of the Pacific coast were submerged. An inland sea of great size covered the central part of North America for some time and extended from the Gulf of Mexico to the Arctic. During the Mesozoic era most of the eastern part of the United States was undergoing erosion which resulted in the reduction of the country to a more or less perfect peneplane, known as the Cretaceous peneplane because it was best developed in that period.

Cretaceous deposits in New York State occur on Long Island and Staten Island. The nonmarine Lower Cretaceous beds (Potomac) are found only along the northwestern border of Long Island and were deposited when slight subsidence produced low-lying flats. Reelevation and erosion were followed by the Upper Cretaceous subsidence of the coastal plain area, permitting marine deposition in a shallow sea. This subsidence included most of Long and Staten Islands. These Cretaceous deposits (Raritan formation of New Jersey etc.) are largely characterized by plant remains, some of which are illustrated in figure 62.

The closing stages of the Upper Cretaceous are marked by great crustal disturbances which resulted in great mountain building from Alaska to the southern end of South America. The Rocky mountains were formed, also the Wasatch and Uinta mountains. North America became practically dry land and the Atlantic and Pacific coasts extended farther out than in Tertiary time following.

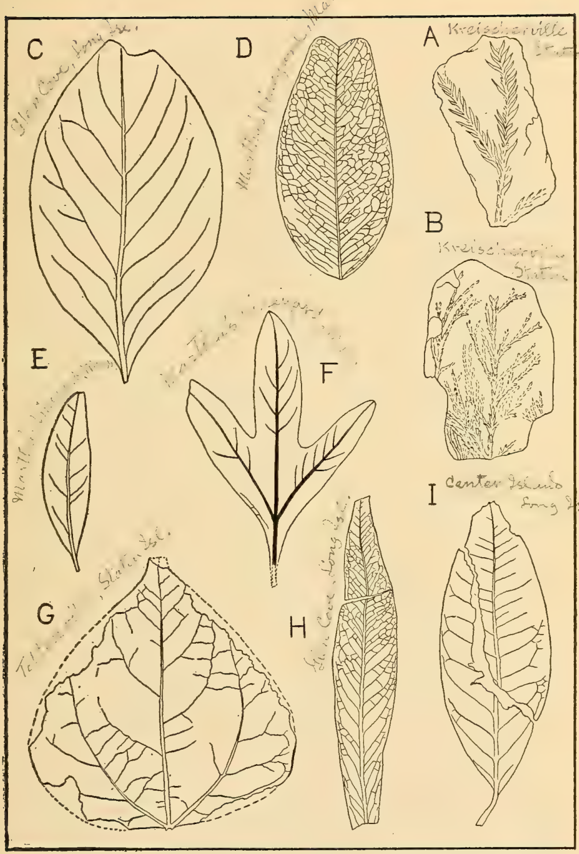


Figure 62 Cretaceous plants. *A Sequoia* (*Sequoia reichenbachi*), x½. *B* Juniper (*Juniperus hypnoides*), x¾. *C* Magnolia (*Magnolia capillini*), x½. *D* Tulip tree (*Liriodendron simplex*), x½. *E* Willow (*Salix meeki*), x½. *F* Sassafras (*Sassafras angustilobum*), x½. *G* Poplar (*Populus harkeriana*), x½. *H* Laurel (*Laurophyllum elegans*), x½. *I* Oak (*Quercus morrisiana*), x½. (After Hollick)

Life of the Mesozoic

The Mesozoic is known as the *Age of Reptiles* and *Medieval Floras.* The first *mammals* appeared in the early Mesozoic and in the later Mesozoic the first *birds* and true *bony fishes* (teleosts). Invertebrate life took on a more modern aspect. The *Foraminifera* reached a great development and were important as rock builders (chalk), especially in the Cretaceous and later in the Tertiary. Modern types of *corals* became established and formed extensive reefs in the Jurassic. New types of echinoderms replaced the old. *Crinoids* were abundant but not diversified in the Jurassic, and certain types of *echinoids* were abundant in the latter part of the era, but *starfishes* were not conspicuous. *Brachiopods* became unimportant. Most of the species belong to genera living today and almost exclusively to three families. There was a rapid development of *pelecypods,* which increased in numbers and variety as brachiopods decreased. *Gastropods* were less simple than Paleozoic forms and many modern types had appeared by the end of the era. Among the *cephalopods* the ammonites had a marvellous development in the Jurassic, and unusual forms appeared with the decline of the race toward the end of the era. *Crustaceans* and *insects* also are of a very modern appearance. All groups of insects except those dependent upon flowering plants for food are represented.

The types of plants now dominant were introduced during the Mesozoic era. *Angiosperms* or flowering plants appeared in the Lower Cretaceous. *Horsetails* that replaced the Carboniferous calamites were very much like those of today. *Cycads* were characteristic of the Triassic and Jurassic; *ferns* were common throughout the era;

conifers lived on the higher lands and were represented by pines, cypresses, yews, araucarias, sequoias etc.

Climate of the Mesozoic

During the Triassic period in North America the climate was on the whole arid, as indicated by the presence of "red beds" and the widespread occurrence of salt and gypsum deposits. Arid conditions probably also existed in the Jurassic but the luxuriant character of the vegetation and the animals point to a warm, moist, subtropical climate, at least during most of the period. The climate of the Cretaceous appears to have been milder than today, and was even temperate or warm temperate in quite northern latitudes (Greenland).

Literature

For this chapter are recommended the various textbooks, Willis and Salisbury ('10), Schuchert ('10), Miller ('24), Hartnagel ('12) and Hollick ('06).

CENOZOIC ERA

The Cenozoic era (modern life) is the last era in the world's history and constitutes about 4 per cent of geologic time. It includes Tertiary (Eocene, Oligocene, Miocene, Pliocene) and Quaternary time, through the Pleistocene or Glacial period.

Tertiary Time

Marine Tertiary deposits occur along the Atlantic and Gulf coasts from Martha's Vineyard island into Texas by way of Alabama and Mississippi, extending northward from the Gulf region as far as the mouth of the

Ohio river. Along the Pacific coast through this time were shifting seas of deposition covering narrow strips along the coast of Mexico, California, Washington and Oregon and northward into Alaska. In the western interior in the region between the Sierra Nevadas and the Rocky mountains and east of the Rockies in the Great Plains region occur continental sediments deposited partly in alluvial fans, partly in lakes, also in flood plains, in deltas and in swamps. Toward the end of Tertiary time there was a period of widespread elevation (Pliocene). The eastern coast of North America was practically the same as today. North of New York the coast extended farther out than at present and the greater part of Florida was under water. Continental deposits occur in wide areas in the coastal plain region along the Atlantic and Gulf coasts. On the Pacific coast sedimentation changed from marine to fresh-water, and in the western interior continental deposits were widely scattered and of limited extent.

There were periods of mountain building and igneous activity during the Tertiary. The greatest volcanic activity since Precambrian times occurred then, particularly in the Miocene period. The early Tertiary (Eocene) was brought to a close by crustal movements. Some mountain ranges already in existence were bowed up, and the Coast ranges began their growth. In the later Eocene, elevation and erosion in Oregon and Washington were accompanied by volcanic activity and extensive lava flows. During Middle Tertiary (Miocene) times there was mountain building accompanied by volcanic activity in Washington, Oregon and Idaho and along the Pacific ranges in California, resulting in great uplift of the Coast ranges of California and Oregon and

the Cascade range of Washington. The old Sierra Nevadas had been peneplaned and the growth of the present ranges begun, and the plateau areas of Utah and Arizona were elevated. Toward the end of Tertiary time (close of Pliocene) the Rocky mountains and Sierra Nevadas began a period of growth which has raised them to their present heights, and thereby converted the Great Plains region into a desert through shutting off the moist winds from the Pacific. The Cascade mountains were apparently peneplaned at this time.

The earliest Tertiary deposits do not occur on Long or Staten Islands but Middle or Late Tertiary deposits are found. Cenozoic deposits in New York State are mainly Quaternary.

Quaternary Time

This is the last great period of earth history. Late Tertiary (Pliocene) and early Quaternary was a time of elevation. The continents stood higher than now and there were broad land connections permitting migration of the animals between the continents. Later, elevation ceased and with subsidence these land connections were broken. The cooling of the climate of Tertiary time culminated in the Pleistocene (Greek: most recent) or Glacial Period. Vast ice sheets spread over much of northern North America and Europe. North America was more affected by the glaciation than any other part of the world. In its greatest extent the ice sheet reached as far south as northern New Jersey and Pennsylvania in the east and to the Ohio river in the Mississippi valley. Thence the front of the ice sheet stretched northwestward through Missouri, Nebraska and the Dakotas and westward through northern Montana, Idaho and

Washington. There were several advances and retreats of the ice front, forming glacial and interglacial stages to which special names have been given. It was during the retreat of this ice sheet that the Great Lakes began their development. Other temporary Pleistocene lakes of large size were developed, as in North Dakota and Minnesota (Lake Agassiz), Nevada and Utah (Lake Bonneville) and northwestern Massachusetts (Lake Bascom). Great Salt Lake, Utah, is today a small remnant of Lake Bonneville. During the Pleistocene there was a great subsidence of the northeastern Atlantic coast and marine waters spread over the St Lawrence valley and Lake Ontario area and through the Lake Champlain and Hudson valleys. Marine shells and skeletons of whales have been found in the sediments deposited. The duration of the Pleistocene or Glacial period has been estimated at 500,000 to 1,000,000 years. The area covered by the ice received a variety of deposits (gravels, sands and clay, in the form of till or boulder clay, drumlins, kames, eskers, sandplains etc.) composed of materials stripped from the regions over which the ice advanced. With the retreat of the ice sheet postglacial or recent time was inaugurated.

New York State has a variety of glacial deposits (continental) but there are also marine and brackish water deposits of gravel, sand and clay found in the St Lawrence, Champlain and Hudson valleys. These deposits contain fossil shells of animals that live in the sea today, and some of these are illustrated in figure 61. It was during the period of the Champlain subsidence that the sea coast acquired nearly its present position. Following the subsidence was the very recent gradual elevation which expelled the Champlain sea. Marine and brackish waters

also disappeared from the St Lawrence and Hudson valleys, leaving New York State as it is today.

Life of the Cenozoic

The Cenozoic era is known as the *Age of Mammals and of Flowering Plants.* Mammals developed rapidly and reached their culmination in the appearance of man in the latter part of the Tertiary. *Mammals* attained their greatest size and variety in the Pliocene and Pleistocene *Amphibians* and *reptiles* have taken on a modern appearance. *Fishes* were abundant in the Tertiary and very similar to those in the sea today. *Foraminifera* among the invertebrates were very abundant and locally in the Tertiary built huge deposits of limestone (*Nummulites*). *Brachiopods* and *crinoids* were rare through the Tertiary; *coral reefs* by later Tertiary had much the distribution of today; *gastropods* and *pelecypods* were abundant and the most numerous of the large invertebrates; *cephalopods* were represented by the Nautilus and squid. *Insects* were numerous, the preserved record probably giving no idea of their total numbers. The vegetable kingdom reached its culmination in *flowering plants.* The general aspect of the forests was much the same as today. Grasses were a very important element in the vegetation because of the part they played in the development of the hoofed animals, the most important branch of the mammals.

In New York State, besides the Pleistocene shells that occur in the marine deposits, fossil mammal remains are found though in no large numbers. These remains include species of fox, bear, seal, giant beaver, peccary, deer, elk, caribou, moose, American bison, horse and mastodon and mammoth.

Climate of the Cenozoic

Early Tertiary (Eocene) climate, as judged by the life of various areas, appears to have been cool to mild temperate. There is evidence of gradual lowering of the temperature through Middle Tertiary time. This cooling continued through late Tertiary (Pliocene) and towards the end of the Pliocene the lowering of the temperature was marked, with perhaps the beginning of glaciation in the highest mountains, and culminated in the Glacial period of the Quaternary.

Literature. For this chapter are recommended the various text books in which other references will be found; also Willis and Salisbury ('10; ch. 10–14) and Schuchert ('10). Among the New York State museum publications are Miller ('24) containing many references, Brigham ('29), Fairchild ('07, '09, '12, '17, '18 etc.), Goldring ('22), Hartnagel ('12), Hartnagel and Bishop ('22) and Woodworth ('05). A very useful reference is "The Last Glaciation" by Ernst Antevs (Amer. Geog. Soc. Research Series No. 17, 1928. 292p.)

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